Instant Help for C# 5.0 Programmers

C# 5.0
Pocket Reference

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C# 5.0 Pocket Reference

When you need answers for programming with C# 5.0, this practical and tightly focused book tells you exactly what you need to know—without long introductions or bloated samples. Easy to browse, it’s ideal as a quick reference or as a guide to get you rapidly up to speed if you already know Java, C++, or an earlier version of C#.

Written by the authors of C# 5.0 in a Nutshell, this book covers C# 5.0 language essentials, including:

- All of C#’s fundamentals
- Advanced topics such as operator overloading, type constraints, covariance and contravariance, iterators, nullable types, operator lifting, lambda expressions, and closures
- LINQ, starting with sequences, lazy execution, and standard query operators, and finishing with a complete reference to query expressions
- Dynamic binding and C# 5.0’s new asynchronous functions
- Unsafe code and pointers, custom attributes, preprocessor directives, and XML documentation

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C# 5.0
Pocket Reference
## Contents

**C# 5.0 Pocket Reference**  
Conventions Used in This Book  
Using Code Examples  
Safari® Books Online  
How to Contact Us  
A First C# Program  
Syntax  
Type Basics  
Numeric Types  
Boolean Type and Operators  
Strings and Characters  
Arrays  
Variables and Parameters  
Expressions and Operators  
Statements  
Namespaces  
Classes  
Inheritance  
The object Type  
Structs  
Access Modifiers  
Interfaces
C# is a general-purpose, type-safe, object-oriented programming language. The goal of the language is programmer productivity. To this end, the language balances simplicity, expressiveness, and performance. The C# language is platform-neutral, but it was written to work well with the Microsoft .NET Framework. C# 5.0 targets .NET Framework 4.5.

NOTE

The programs and code snippets in this book mirror those in Chapters 2 through 4 of C# 5.0 in a Nutshell and are all available as interactive samples in LINQPad. Working through these samples in conjunction with the book accelerates learning in that you can edit the samples and instantly see the results without needing to set up projects and solutions in Visual Studio.

To download the samples, click the Samples tab in LINQPad and click “Download more samples”. LINQPad is free—go to http://www.linqpad.net.
Conventions Used in This Book

The following typographical conventions are used in this book:

Italic
Indicates new terms, URLs, email addresses, filenames, and file extensions.

Constant width
Used for program listings, as well as within paragraphs to refer to program elements such as variable or function names, databases, data types, environment variables, statements, and keywords.

Constant width bold
Shows commands or other text that should be typed literally by the user.

Constant width italic
Shows text that should be replaced with user-supplied values or by values determined by context.

TIP
This icon signifies a tip, suggestion, or general note.

CAUTION
This icon indicates a warning or caution.

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A First C# Program

Here is a program that multiplies 12 by 30, and prints the result, 360, to the screen. The double forward slash indicates that the remainder of a line is a comment.

```csharp
using System;                 // Importing namespace

class Test                    // Class declaration
{
    static void Main()          // Method declaration
    {
```
```csharp
int x = 12 * 30; // Statement 1
Console.WriteLine(x); // Statement 2
}```}

At the heart of this program lie two statements. Statements in C# execute sequentially and are terminated by a semicolon. The first statement computes the expression 12 * 30 and stores the result in a local variable, named x, which is an integer type. The second statement calls the Console class’s WriteLine method to print the variable x to a text window on the screen.

A method performs an action in a series of statements called a statement block—a pair of braces containing zero or more statements. We defined a single method named Main.

Writing higher-level functions that call upon lower-level functions simplifies a program. We can refactor our program with a reusable method that multiplies an integer by 12, as follows:

```csharp
using System;

class Test
{
    static void Main()
    {
        Console.WriteLine(FeetToInches(30)); // 360
        Console.WriteLine(FeetToInches(100)); // 1200
    }

    static int FeetToInches(int feet)
    {
        int inches = feet * 12;
        return inches;
    }
}
```

A method can receive input data from the caller by specifying parameters and output data back to the caller by specifying a return type. We defined a method called FeetToInches that has a parameter for inputting feet, and a return type for outputting inches, both of type int (integer).

The literals 30 and 100 are the arguments passed to the FeetToInches method. The Main method in our example has empty
parentheses because it has no parameters, and is void because it doesn’t return any value to its caller. C# recognizes a method called Main as signaling the default entry point of execution. The Main method may optionally return an integer (rather than void) in order to return a value to the execution environment. The Main method can also optionally accept an array of strings as a parameter (that will be populated with any arguments passed to the executable). For example:

```csharp
static int Main (string[] args) {...}
```

---

**NOTE**

An array (such as `string[]`) represents a fixed number of elements of a particular type (for more information, see “Arrays” on page 32).

---

Methods are one of several kinds of functions in C#. Another kind of function we used was the * operator, used to perform multiplication. There are also constructors, properties, events, indexers, and finalizers.

In our example, the two methods are grouped into a class. A class groups function members and data members to form an object-oriented building block. The Console class groups members that handle command-line input/output functionality, such as the WriteLine method. Our Test class groups two methods—the Main method and the FeetToInches method. A class is a kind of type, which we will examine in the section “Type Basics” on page 11.

At the outermost level of a program, types are organized into namespaces. The using directive was used to make the System namespace available to our application, to use the Console class. We could define all our classes within the TestPrograms namespace as follows:

```csharp
using System;

namespace TestPrograms
{
```
class Test {...}
class Test2 {...}
}

The .NET Framework is organized into nested namespaces. For example, this is the namespace that contains types for handling text:

    using System.Text;

The using directive is there for convenience; you can also refer to a type by its fully qualified name, which is the type name prefixed with its namespace, such as System.Text.StringBuilder.

**Compilation**

The C# compiler collects source code, specified as a set of files with the .cs extension, into an assembly. An assembly is the unit of packaging and deployment in .NET. An assembly can be either an application or a library. A normal console or Windows application has a `Main` method and is an .exe file. A library is a .dll and is equivalent to an .exe without an entry point. Its purpose is to be called upon (referenced) by an application or by other libraries. The .NET Framework is a set of libraries.

The name of the C# compiler is `csc.exe`. You can either use an integrated development environment (IDE), such as Visual Studio, to compile, or call `csc` manually from the command line. To compile manually, first save a program to a file such as `MyFirstProgram.cs`, and then go to the command line and invoke `csc` (located under `%SystemRoot%\Microsoft.NET\Framework\<framework-version>` where `%SystemRoot%` is your Windows directory) as follows:

    csc MyFirstProgram.cs

This produces an application named `MyFirstProgram.exe`.

To produce a library (.dll), do the following:

    csc /target:library MyFirstProgram.cs
Syntax

C# syntax is inspired by C and C++ syntax. In this section, we will describe C#'s elements of syntax, using the following program:

```csharp
using System;

class Test
{
    static void Main()
    {
        int x = 12 * 30;
        Console.WriteLine(x);
    }
}
```

Identifiers and Keywords

**Identifiers** are names that programmers choose for their classes, methods, variables, and so on. These are the identifiers in our example program, in the order they appear:

```
System Test Main x Console WriteLine
```

An identifier must be a whole word, essentially made up of Unicode characters starting with a letter or underscore. C# identifiers are case-sensitive. By convention, parameters, local variables, and private fields should be in camel case (e.g., `myVariable`), and all other identifiers should be in Pascal case (e.g., `MyMethod`).

**Keywords** are names reserved by the compiler that you can’t use as identifiers. These are the keywords in our example program:

```
using class static void int
```
Here is the full list of C# keywords:

abstract enum long stackalloc
as event namespace static
base explicit new string
bool extern null struct
break false object switch
byte finally operator this
case fixed out throw
catch float override true
char for params try
checked foreach private typeof
class goto protected uint
cost if public ulong
continue implicit readonly unchecked
decimal in ref unsafe
default int return ushort
delegate interface sbyte using
do internal sealed virtual
double is short void
else lock sizeof while

**Avoiding conflicts**

If you really want to use an identifier that clashes with a keyword, you can do so by qualifying it with the @ prefix. For instance:

```csharp
class class {...}      // Illegal
class @class {...}      // Legal
```

The @ symbol doesn’t form part of the identifier itself. So @myVariable is the same as myVariable.
Contextual keywords

Some keywords are contextual, meaning they can also be used as identifiers—without an @ symbol. These are:

- add
- ascending
- async
- await
- by
- descending
- dynamic
- equals
- from
- get
- global
- group
- in
- join
- let
- on
- orderby
- partial
- remove
- select
- set
- value
- var
- where
- yield

With contextual keywords, ambiguity cannot arise within the context in which they are used.

Literals, Punctuators, and Operators

Literals are primitive pieces of data lexically embedded into the program. The literals in our example program are 12 and 30. Punctuators help demarcate the structure of the program. The punctuators in our program are {, }, and ;.

The braces group multiple statements into a statement block. The semicolon terminates a (nonblock) statement. Statements can wrap multiple lines:

```csharp
Console.WriteLine(1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9 + 10);
```

An operator transforms and combines expressions. Most operators in C# are denoted with a symbol, such as the multiplication operator, *. The operators in our program are:  

- .
- ()
- *
- =

A period denotes a member of something (or a decimal point with numeric literals). Parentheses are used when declaring or calling a method; empty parentheses are used when the method accepts no arguments. The equals sign performs
assignment (the double equals, ==, performs equality comparison).

Comments

C# offers two different styles of source-code documentation: single-line comments and multiline comments. A single-line comment begins with a double forward slash and continues until the end of the line. For example:

```csharp
int x = 3;   // Comment about assigning 3 to x
```

A multiline comment begins with /* and ends with */. For example:

```csharp
int x = 3;   /* This is a comment that
spans two lines */
```

Comments may embed XML documentation tags (see “XML Documentation” on page 196).

Type Basics

A type defines the blueprint for a value. In our example, we used two literals of type `int` with values 12 and 30. We also declared a variable of type `int` whose name was `x`.

A variable denotes a storage location that can contain different values over time. In contrast, a constant always represents the same value (more on this later).

All values in C# are an instance of a specific type. The meaning of a value, and the set of possible values a variable can have, is determined by its type.

Predefined Type Examples

Predefined types (also called built-in types) are types that are specially supported by the compiler. The `int` type is a predefined type for representing the set of integers that fit into 32 bits of memory, from \(-2^{31}\) to \(2^{31}-1\). We can perform func-
tions such as arithmetic with instances of the `int` type as follows:

```csharp
int x = 12 * 30;
```

Another predefined C# type is `string`. The `string` type represents a sequence of characters, such as “.NET” or “http://oreilly.com”. We can work with strings by calling functions on them as follows:

```csharp
string message = "Hello world";
string upperMessage = message.ToUpper();
Console.WriteLine (upperMessage);       // HELLO WORLD
```

```csharp
int x = 2012;
message = message + x.ToString();
Console.WriteLine (message);         // Hello world2012
```

The predefined `bool` type has exactly two possible values: `true` and `false`. The `bool` type is commonly used to conditionally branch execution flow with an `if` statement. For example:

```csharp
bool simpleVar = false;
if (simpleVar)
    Console.WriteLine ("This will not print");
```

```csharp
int x = 5000;
bool lessThanAMile = x < 5280;
if (lessThanAMile)
    Console.WriteLine ("This will print");
```

---

**NOTE**

The `System` namespace in the .NET Framework contains many important types that are not predefined by C# (e.g., `DateTime`).

---

**Custom Type Examples**

Just as we can build complex functions from simple functions, we can build complex types from primitive types. In this example, we will define a custom type named `UnitConverter`—a class that serves as a blueprint for unit conversions:
using System;

public class UnitConverter
{
   int ratio;                             // Field

   public UnitConverter (int unitRatio)   // Constructor
   {
      ratio = unitRatio;
   }

   public int Convert (int unit)          // Method
   {
      return unit * ratio;
   }
}

class Test
{
   static void Main()
   {
      UnitConverter feetToInches = new UnitConverter(12);
      UnitConverter milesToFeet = new UnitConverter(5280);

      Console.Write (feetToInches.Convert(30));   // 360
      Console.Write (feetToInches.Convert(100));  // 1200
      Console.Write (feetToInches.Convert(milesToFeet.Convert(1)));  // 63360
   }
}

Members of a type

A type contains data members and function members. The data member of UnitConverter is the field called ratio. The function members of UnitConverter are the Convert method and the UnitConverter’s constructor.

Symmetry of predefined types and custom types

A beautiful aspect of C# is that predefined types and custom types have few differences. The predefined int type serves as a blueprint for integers. It holds data—32 bits—and provides function members that use that data, such as ToString. Similarly, our custom UnitConverter type acts as a blueprint for unit
conversions. It holds data—the ratio—and provides function members to use that data.

**Constructors and instantiation**

Data is created by *instantiating* a type. Predefined types can be instantiated simply by using a literal such as 12 or "Hello, world".

The `new` operator creates instances of a custom type. We started our `Main` method by creating two instances of the `UnitConverter` type. Immediately after the `new` operator instantiates an object, the object’s *constructor* is called to perform initialization. A constructor is defined like a method, except that the method name and return type are reduced to the name of the enclosing type:

```csharp
public UnitConverter (int unitRatio)   // Constructor
{
    ratio = unitRatio;
}
```

**Instance versus static members**

The data members and function members that operate on the *instance* of the type are called instance members. The `UnitConverter`’s `Convert` method and the `int`’s `ToString` method are examples of instance members. By default, members are instance members.

Data members and function members that don’t operate on the instance of the type, but rather on the type itself, must be marked as `static`. The `Test.Main` and `Console.WriteLine` methods are static methods. The `Console` class is actually a *static class*, which means all its members are static. You never actually create instances of a `Console`—one console is shared across the whole application.

To contrast instance with static members, the instance field `Name` pertains to an instance of a particular `Panda`, whereas `Population` pertains to the set of all `Panda` instances:
public class Panda
{
    public string Name;           // Instance field
    public static int Population; // Static field

    public Panda (string n)       // Constructor
    {
        Name = n;                   // Assign instance field
        Population = Population+1;  // Increment static field
    }
}

The following code creates two instances of the Panda, prints their names, and then prints the total population:

    Panda p1 = new Panda ("Pan Dee");
    Panda p2 = new Panda ("Pan Dah");

    Console.WriteLine (p1.Name);      // Pan Dee
    Console.WriteLine (p2.Name);      // Pan Dah

    Console.WriteLine (Panda.Population);   // 2

The public keyword

The public keyword exposes members to other classes. In this example, if the Name field in Panda was not public, the Test class could not access it. Marking a member public is how a type communicates: “Here is what I want other types to see—everything else is my own private implementation details.” In object-oriented terms, we say that the public members encapsulate the private members of the class.

Conversions

C# can convert between instances of compatible types. A conversion always creates a new value from an existing one. Conversions can be either implicit or explicit: implicit conversions happen automatically whereas explicit conversions require a cast. In the following example, we implicitly convert an int to a long type (which has twice the bitwise capacity of an int) and explicitly cast an int to a short type (which has half the bitwise capacity of an int):
int x = 12345; // int is a 32-bit integer
long y = x;    // Implicit conversion to 64-bit int
short z = (short)x; // Explicit conversion to 16-bit int

In general, implicit conversions are allowed when the compiler can guarantee they will always succeed without loss of information. Otherwise, you must perform an explicit cast to convert between compatible types.

**Value Types Versus Reference Types**

C# types can be divided into *value types* and *reference types*. *Value types* comprise most built-in types (specifically, all numeric types, the `char` type, and the `bool` type) as well as custom `struct` and `enum` types. *Reference types* comprise all class, array, delegate, and interface types.

The fundamental difference between value types and reference types is how they are handled in memory.

**Value types**

The content of a *value-type* variable or constant is simply a value. For example, the content of the built-in value type, `int`, is 32 bits of data.

You can define a custom value type with the `struct` keyword (see Figure 1):

```csharp
public struct Point { public int X, Y; }
```

![Figure 1. A value-type instance in memory](image)

The assignment of a value-type instance always *copies* the instance. For example:
Point p1 = new Point();
p1.X = 7;

Point p2 = p1; // Assignment causes copy

Console.WriteLine (p1.X); // 7
Console.WriteLine (p2.X); // 7

p1.X = 9; // Change p1.X
Console.WriteLine (p1.X); // 9
Console.WriteLine (p2.X); // 7

Figure 2 shows that p1 and p2 have independent storage.

Figure 2. Assignment copies a value-type instance

Reference types

A reference type is more complex than a value type, having two parts: an object and the reference to that object. The content of a reference-type variable or constant is a reference to an object that contains the value. Here is the Point type from our previous example rewritten as a class (see Figure 3):

```csharp
public class Point { public int X, Y; }
```

Figure 3. A reference-type instance in memory
Assigning a reference-type variable copies the reference, not the object instance. This allows multiple variables to refer to the same object—something not ordinarily possible with value types. If we repeat the previous example, but with Point now a class, an operation via p1 affects p2:

```csharp
Point p1 = new Point();
p1.X = 7;

Point p2 = p1; // Copies p1 reference

Console.WriteLine (p1.X); // 7
Console.WriteLine (p2.X); // 7

p1.X = 9; // Change p1.X
Console.WriteLine (p1.X); // 9
Console.WriteLine (p2.X); // 9
```

Figure 4 shows that p1 and p2 are two references that point to the same object.

![Figure 4. Assignment copies a reference](image)

**Null**

A reference can be assigned the literal `null`, indicating that the reference points to no object. Assuming `Point` is a class:

```csharp
Point p = null;
Console.WriteLine (p == null); // True
```

Accessing a member of a null reference generates a runtime error:

```csharp
Console.WriteLine (p.X); // NullReferenceException
```
In contrast, a value type cannot ordinarily have a null value:

```csharp
struct Point {...}
...
Point p = null;  // Compile-time error
int x = null;    // Compile-time error
```

---

**NOTE**

C# has a special construct called *nullable types* for representing value-type nulls (for more information, see “Nullable Types” on page 132).

---

**Predefined Type Taxonomy**

The predefined types in C# are:

- **Value types**
  - Numeric
    - Signed integer (sbyte, short, int, long)
    - Unsigned integer (byte, ushort, uint, ulong)
    - Real number (float, double, decimal)
  - Logical (bool)
  - Character (char)

- **Reference types**
  - String (string)
  - Object (object)

Predefined types in C# alias Framework types in the *System* namespace. There is only a syntactic difference between these two statements:

```csharp
int i = 5;
System.Int32 i = 5;
```

The set of predefined *value* types excluding *decimal* are known as *primitive types* in the Common Language Runtime (CLR). Primitive types are so called because they are supported
directly via instructions in compiled code, which usually translates to direct support on the underlying processor.

**Numeric Types**

C# has the following predefined numeric types:

<table>
<thead>
<tr>
<th>C# type</th>
<th>System type</th>
<th>Suffix</th>
<th>Size</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Integral—signed</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sbyte</td>
<td>SByte</td>
<td>8 bits</td>
<td>8 bits</td>
<td>$-2^7$ to $2^7-1$</td>
</tr>
<tr>
<td>short</td>
<td>Int16</td>
<td>16 bits</td>
<td>16 bits</td>
<td>$-2^{15}$ to $2^{15}-1$</td>
</tr>
<tr>
<td>int</td>
<td>Int32</td>
<td>32 bits</td>
<td>32 bits</td>
<td>$-2^{31}$ to $2^{31}-1$</td>
</tr>
<tr>
<td>long</td>
<td>Int64</td>
<td>L</td>
<td>64 bits</td>
<td>$-2^{63}$ to $2^{63}-1$</td>
</tr>
<tr>
<td><strong>Integral—unsigned</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>byte</td>
<td>Byte</td>
<td>8 bits</td>
<td>8 bits</td>
<td>0 to $2^8-1$</td>
</tr>
<tr>
<td>ushort</td>
<td>UInt16</td>
<td>16 bits</td>
<td>16 bits</td>
<td>0 to $2^{16}-1$</td>
</tr>
<tr>
<td>uint</td>
<td>UInt32</td>
<td>U</td>
<td>32 bits</td>
<td>0 to $2^{32}-1$</td>
</tr>
<tr>
<td>ulong</td>
<td>UInt64</td>
<td>UL</td>
<td>64 bits</td>
<td>0 to $2^{64}-1$</td>
</tr>
<tr>
<td><strong>Real</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>float</td>
<td>Single</td>
<td>F</td>
<td>32 bits</td>
<td>$\pm \sim10^{-45}$ to $10^{38}$</td>
</tr>
<tr>
<td>double</td>
<td>Double</td>
<td>D</td>
<td>64 bits</td>
<td>$\pm \sim10^{-324}$ to $10^{308}$</td>
</tr>
<tr>
<td>decimal</td>
<td>Decimal</td>
<td>M</td>
<td>128 bits</td>
<td>$\pm \sim10^{-28}$ to $10^{28}$</td>
</tr>
</tbody>
</table>

Of the *integral* types, `int` and `long` are first-class citizens and are favored by both C# and the runtime. The other integral types are typically used for interoperability or when space efficiency is paramount.

Of the *real* number types, `float` and `double` are called floating-point types and are typically used for scientific calculations. The `decimal` type is typically used for financial calculations, where base-10-accurate arithmetic and high precision are required. (Technically, `decimal` is a floating-point type too, although it’s not generally referred to as such.)
**Numeric Literals**

*Integral literals* can use decimal or hexadecimal notation; hexadecimal is denoted with the `0x` prefix (e.g., `0x7f` is equivalent to `127`). *Real literals* may use decimal or exponential notation such as `1E06`.

**Numeric literal type inference**

By default, the compiler *infers* a numeric literal to be either *double* or an integral type:

- If the literal contains a decimal point or the exponential symbol (`E`), it is a *double*.
- Otherwise, the literal’s type is the first type in this list that can fit the literal’s value: int, uint, long, and ulong.

For example:

```csharp
Console.Write (       1.0.GetType());  // Double (double)
Console.Write (      1E06.GetType());  // Double (double)
Console.Write (         1.GetType());  // Int32 (int)
Console.Write (0xF0000000.GetType());  // UInt32 (uint)
```

**Numeric suffixes**

The *numeric suffixes* listed in the preceding table explicitly define the type of a literal:

```csharp
decimal d = 3.5M;   // M = decimal (case-insensitive)
```

The suffixes `U` and `L` are rarely necessary, because the `uint`, `long`, and `ulong` types can nearly always be either inferred or implicitly converted from `int`:

```csharp
long i = 5;       // Implicit conversion from int to long
```

The `D` suffix is technically redundant, in that all literals with a decimal point are inferred to be double (and you can always add a decimal point to a numeric literal). The `F` and `M` suffixes are the most useful and are mandatory when specifying fractional `float` or `decimal` literals. Without suffixes, the following would not compile, because `4.5` would be inferred to be of type `double`, which has no implicit conversion to `float` or `decimal`:
float f = 4.5F;       // Won't compile without suffix
decimal d = -1.23M;   // Won't compile without suffix

Numeric Conversions

Integral to integral conversions

Integral conversions are implicit when the destination type can represent every possible value of the source type. Otherwise, an explicit conversion is required. For example:

```csharp
int x = 12345;       // int is a 32-bit integral
long y = x;          // Implicit conversion to 64-bit int
short z = (short)x;  // Explicit conversion to 16-bit int
```

Real to real conversions

A float can be implicitly converted to a double, because a double can represent every possible float value. The reverse conversion must be explicit.

Conversions between decimal and other real types must be explicit.

Real to integral conversions

Conversions from integral types to real types are implicit, whereas the reverse must be explicit. Converting from a floating-point to an integral truncates any fractional portion; to perform rounding conversions, use the static System.Convert class.

A caveat is that implicitly converting a large integral type to a floating-point type preserves magnitude but may occasionally lose precision:

```csharp
int i1 = 100000001;
float f = i1;       // Magnitude preserved, precision lost
int i2 = (int)f;    // 100000000
```
Arithmetic Operators

The arithmetic operators (+, -, *, /, %) are defined for all numeric types except the 8- and 16-bit integral types. The % operator evaluates the remainder after division.

Increment and Decrement Operators

The increment and decrement operators (++, --) increment and decrement numeric types by 1. The operator can either precede or follow the variable, depending on whether you want the variable to be updated before or after the expression is evaluated. For example:

```csharp
int x = 0;
Console.WriteLine(x++);   // Outputs 0; x is now 1
Console.WriteLine (++x);  // Outputs 2; x is now 2
Console.WriteLine (--x);  // Outputs 1; x is now 1
```

Specialized Integral Operations

Integral division

Division operations on integral types always truncate remainders (round toward zero). Dividing by a variable whose value is zero generates a runtime error (a DivideByZeroException). Dividing by the literal or constant 0 generates a compile-time error.

Integral overflow

At runtime, arithmetic operations on integral types can overflow. By default, this happens silently—no exception is thrown and the result exhibits wraparound behavior, as though the computation was done on a larger integer type and the extra significant bits discarded. For example, decrementing the minimum possible int value results in the maximum possible int value:

```csharp
int a = int.MinValue; a--;  
Console.WriteLine (a == int.MaxValue); // True
```
The checked and unchecked operators

The checked operator tells the runtime to generate an OverflowException rather than overflowing silently when an integral expression or statement exceeds the arithmetic limits of that type. The checked operator affects expressions with the +, −, (unary) −, +, −, *, /, and explicit conversion operators between integral types.

You can use checked around either an expression or a statement block. For example:

```csharp
int a = 1000000, b = 1000000;

int c = checked (a * b);   // Checks just the expression

checked                          // Checks all expressions
{                                // in statement block.
    c = a * b;
    ...
}
```

You can make arithmetic overflow checking the default for all expressions in a program by compiling with the `/checked+` command-line switch (in Visual Studio, go to Advanced Build Settings). If you then need to disable overflow checking just for specific expressions or statements, you can do so with the unchecked operator.

Bitwise operators

C# supports the following bitwise operators:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Meaning</th>
<th>Sample expression</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>~</td>
<td>Complement</td>
<td>~0xfU</td>
<td>0xfffffffff0U</td>
</tr>
<tr>
<td>&amp;</td>
<td>And</td>
<td>0xf0 &amp; 0x33</td>
<td>0x30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Or</td>
<td>0xf0</td>
</tr>
<tr>
<td>^</td>
<td>Exclusive Or</td>
<td>0xff00 ^ 0x0ff0</td>
<td>0xf0f0</td>
</tr>
<tr>
<td>&lt;&lt;</td>
<td>Shift left</td>
<td>0x20 &lt;&lt; 2</td>
<td>0x80</td>
</tr>
<tr>
<td>&gt;&gt;</td>
<td>Shift right</td>
<td>0x20 &gt;&gt; 1</td>
<td>0x10</td>
</tr>
</tbody>
</table>
8- and 16-Bit Integrals

The 8- and 16-bit integral types are byte, sbyte, short, and ushort. These types lack their own arithmetic operators, so C# implicitly converts them to larger types as required. This can cause a compilation error when trying to assign the result back to a small integral type:

```csharp
short x = 1, y = 1;
short z = x + y;          // Compile-time error
```

In this case, x and y are implicitly converted to int so that the addition can be performed. This means the result is also an int, which cannot be implicitly cast back to a short (because it could cause loss of data). To make this compile, we must add an explicit cast:

```csharp
short z = (short) (x + y);   // OK
```

Special Float and Double Values

Unlike integral types, floating-point types have values that certain operations treat specially. These special values are NaN (Not a Number), +∞, –∞, and –0. The float and double classes have constants for NaN, +∞, and –∞ (as well as other values including MaxValue, MinValue, and Epsilon). For example:

```csharp
Console.Write (double.NegativeInfinity);   // -Infinity
```

Dividing a nonzero number by zero results in an infinite value:

```csharp
Console.WriteLine ( 1.0 /  0.0);   //  Infinity
Console.WriteLine (-1.0 /  0.0);   // -Infinity
Console.WriteLine ( 1.0 / -0.0);   // -Infinity
Console.WriteLine (-1.0 / -0.0);   //  Infinity
```

Dividing zero by zero, or subtracting infinity from infinity, results in a NaN:

```csharp
Console.Write ( 0.0 / 0.0);                 //  NaN
Console.Write ((1.0 / 0.0) – (1.0 / 0.0));  //  NaN
```

When using ==, a NaN value is never equal to another value, even another NaN value. To test whether a value is NaN, you must use the float.IsNaN or double.IsNaN method:
Console.WriteLine (0.0 / 0.0 == double.NaN);  // False
Console.WriteLine (double.IsNaN (0.0 / 0.0));   // True

When using object.Equals, however, two NaN values are equal:

    bool isTrue = object.Equals (0.0/0.0, double.NaN);

### double Versus decimal

For scientific computations (such as computing spatial coordinates), double is useful. decimal is useful for financial computations and values that are “man-made” rather than the result of real-world measurements. Here’s a summary of the differences:

<table>
<thead>
<tr>
<th>Feature</th>
<th>double</th>
<th>decimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal representation</td>
<td>Base 2</td>
<td>Base 10</td>
</tr>
<tr>
<td>Precision</td>
<td>15-16 significant figures</td>
<td>28-29 significant figures</td>
</tr>
<tr>
<td>Range</td>
<td>±(~10(^{-324}) to ~10(^{308}))</td>
<td>±(~10(^{-28}) to ~10(^{28}))</td>
</tr>
<tr>
<td>Special values</td>
<td>+0, –0, +∞, –∞, and NaN</td>
<td>None</td>
</tr>
<tr>
<td>Speed</td>
<td>Native to processor</td>
<td>Non-native to processor (about 10 times slower than double)</td>
</tr>
</tbody>
</table>

### Real Number Rounding Errors

float and double internally represent numbers in base 2. For this reason, most literals with a fractional component (which are in base 10) will not be represented precisely:

```csharp
    float tenth = 0.1f;                      // Not quite 0.1
    float one   = 1f;
    Console.WriteLine (one - tenth * 10f);    // -1.490116E-08
```

This is why float and double are bad for financial calculations. In contrast, decimal works in base 10 and so can precisely represent fractional numbers such as 0.1 (whose base 10 representation is nonrecurring).
Boolean Type and Operators

C#'s `bool` type (aliasing the `System.Boolean` type) is a logical value that can be assigned the literal `true` or `false`.

Although a Boolean value requires only one bit of storage, the runtime will use one byte of memory, since this is the minimum chunk that the runtime and processor can efficiently work with. To avoid space inefficiency in the case of arrays, the Framework provides a `BitArray` class in the `System.Collections` namespace that is designed to use just one bit per Boolean value.

Equality and Comparison Operators

`==` and `!=` test for equality and inequality of any type, and always return a `bool` value. Value types typically have a very simple notion of equality:

```csharp
int x = 1, y = 2, z = 1;
Console.WriteLine(x == y);      // False
Console.WriteLine(x == z);      // True
```

For reference types, equality, by default, is based on `reference`, as opposed to the actual `value` of the underlying object. Therefore, two instances of an object with identical data are not considered equal unless the `==` operator for that type is specially overloaded to that effect (for more information, see the sections “The object Type” on page 79 and “Operator Overloading” on page 136).

The equality and comparison operators, `==`, `!=`, `<`, `>`, `>=`, and `<=`, work for all numeric types, but should be used with caution with real numbers (see the section “Real Number Rounding Errors” on page 26 on the previous page). The comparison operators also work on `enum` type members, by comparing their underlying integral values.
Conditional Operators

The `&&` and `||` operators test for *and* and *or* conditions. They are frequently used in conjunction with the `!` operator, which expresses *not*. In this example, the `UseUmbrella` method returns `true` if it’s rainy or sunny (to protect us from the rain or the sun), as long as it’s not also windy (since umbrellas are useless in the wind):

```csharp
static bool UseUmbrella (bool rainy, bool sunny, bool windy)
{
    return !windy && (rainy || sunny);
}
```

The `&&` and `||` operators *short-circuit* evaluation when possible. In the preceding example, if it is windy, the expression `(rainy || sunny)` is not even evaluated. Short-circuiting is essential in allowing expressions such as the following to run without throwing a `NullReferenceException`:

```csharp
if (sb != null && sb.Length > 0) ...  
```

The `&` and `|` operators also test for *and* and *or* conditions:

```csharp
return !windy & (rainy | sunny);
```

The difference is that they do not short-circuit. For this reason, they are rarely used in place of conditional operators.

The ternary conditional operator (simply called the *conditional operator*) has the form `q ? a : b`, where if condition `q` is true, `a` is evaluated, else `b` is evaluated. For example:

```csharp
static int Max (int a, int b)
{
    return (a > b) ? a : b;
}
```

The conditional operator is particularly useful in LINQ queries.
Strings and Characters

C#'s char type (aliasing the System.Char type) represents a Unicode character and occupies two bytes. A char literal is specified inside single quotes:

```csharp
char c = 'A';       // Simple character
```

Escape sequences express characters that cannot be expressed or interpreted literally. An escape sequence is a backslash followed by a character with a special meaning. For example:

```csharp
char newLine = '\n';
char backSlash = '\\';
```

The escape sequence characters are:

<table>
<thead>
<tr>
<th>Char</th>
<th>Meaning</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>'\ '</td>
<td>Single quote</td>
<td>0x0027</td>
</tr>
<tr>
<td>'&quot; '</td>
<td>Double quote</td>
<td>0x0022</td>
</tr>
<tr>
<td>''</td>
<td>Backslash</td>
<td>0x005C</td>
</tr>
<tr>
<td>'\0'</td>
<td>Null</td>
<td>0x0000</td>
</tr>
<tr>
<td>'\a'</td>
<td>Alert</td>
<td>0x0007</td>
</tr>
<tr>
<td>'\b'</td>
<td>Backspace</td>
<td>0x0008</td>
</tr>
<tr>
<td>'\f'</td>
<td>Form feed</td>
<td>0x000C</td>
</tr>
<tr>
<td>'\n'</td>
<td>New line</td>
<td>0x000A</td>
</tr>
<tr>
<td>'\r'</td>
<td>Carriage return</td>
<td>0x000D</td>
</tr>
<tr>
<td>'\t'</td>
<td>Horizontal tab</td>
<td>0x0009</td>
</tr>
<tr>
<td>'\v'</td>
<td>Vertical tab</td>
<td>0x000B</td>
</tr>
</tbody>
</table>

The \u (or \x) escape sequence lets you specify any Unicode character via its four-digit hexadecimal code:

```csharp
char copyrightSymbol = '\u00A9';
char omegaSymbol     = \u03A9;
char newLine         = '\u000A';
```

Strings and Characters | 29
An implicit conversion from a `char` to a numeric type works for the numeric types that can accommodate an unsigned `short`. For other numeric types, an explicit conversion is required.

**String Type**

C#’s `string` type (aliasing the `System.String` type) represents an immutable sequence of Unicode characters. A string literal is specified inside double quotes:

```csharp
string a = "Heat";
```

---

**NOTE**

`string` is a reference type, rather than a value type. Its equality operators, however, follow value-type semantics:

```csharp
string a = "test", b = "test";
Console.Write (a == b);  // True
```

The escape sequences that are valid for `char` literals also work inside strings:

```csharp
string a = "Here's a tab: \t";
```

The cost of this is that whenever you need a literal backslash, you must write it twice:

```csharp
string a1 = "\\server\fileshare\helloworld.cs";
```

To avoid this problem, C# allows *verbatim* string literals. A verbatim string literal is prefixed with `@` and does not support escape sequences. The following verbatim string is identical to the preceding one:

```csharp
string a2 = @"\server\fileshare\helloworld.cs";
```

A verbatim string literal can also span multiple lines. You can include the double-quote character in a verbatim literal by writing it twice.
**String concatenation**

The + operator concatenates two strings:

```csharp
string s = "a" + "b";
```

One of the operands may be a nonstring value, in which case `ToString` is called on that value. For example:

```csharp
string s = "a" + 5;  // a5
```

Using the + operator repeatedly to build up a string can be inefficient: a better solution is to use the `System.Text.StringBuilder` type—this represents a mutable (editable) string, and has methods to efficiently `Append`, `Insert`, `Remove`, and `Replace` substrings.

**String comparisons**

`string` does not support `<` and `>` operators for comparisons. You must instead use `string`’s `CompareTo` method, which returns a positive number, a negative number, or zero, depending on whether the first value comes after, before, or alongside the second value:

```csharp
Console.Write ("Boston".CompareTo ("Austin"));  // 1
Console.Write ("Boston".CompareTo ("Boston"));  // 0
Console.Write ("Boston".CompareTo ("Chicago")); // -1
```

**Searching within strings**

`string`’s indexer returns a character at a specified position:

```csharp
Console.Write ("word"[2]);  // r
```

The `IndexOf` and `LastIndexOf` methods search for a character within the string. The `Contains`, `StartsWith`, and `EndsWith` methods search for a substring within the string.

**Manipulating strings**

Because `string` is immutable, all the methods that “manipulate” a string return a new one, leaving the original untouched:

- `Substring` extracts a portion of a string.
• Insert and Remove insert and remove characters at a specified position.
• PadLeft and PadRight add whitespace.
• TrimStart, TrimEnd, and Trim remove whitespace.

The string class also defines ToUpper and ToLower methods for changing case, a Split method to split a string into substrings (based on supplied delimiters), and a static Join method to join substrings back into a string.

Arrays

An array represents a fixed number of elements of a particular type. The elements in an array are always stored in a contiguous block of memory, providing highly efficient access.

An array is denoted with square brackets after the element type. The following declares an array of five characters:

```csharp
char[] vowels = new char[5];
```

Square brackets also index the array, accessing a particular element by position:

```csharp
```

```csharp
Console.WriteLine (vowels[1]); // e
```

This prints “e” because array indexes start at 0. We can use a for loop statement to iterate through each element in the array. The for loop in this example cycles the integer `i` from 0 to 4:

```csharp
for (int i = 0; i < vowels.Length; i++)
    Console.Write (vowels[i]); // aeiou
```

Arrays also implement IEnumerable<T> (see “Enumeration and Iterators” on page 126), so you can also enumerate members with the foreach statement:

```csharp
foreach (char c in vowels) Console.Write (c); // aeiou
```

All array indexing is bounds-checked by the runtime. An IndexOutOfRangeException is thrown if you use an invalid index:
The `Length` property of an array returns the number of elements in the array. Once an array has been created, its `Length` cannot be changed. The `System.Collection` namespace and subnamespaces provide higher-level data structures, such as dynamically sized arrays and dictionaries.

An **array initialization expression** lets you declare and populate an array in a single step:

```csharp
char[] vowels = new char[] {'a','e','i','o','u'};
```

or simply:

```csharp
char[] vowels = {'a','e','i','o','u'};
```

All arrays inherit from the `System.Array` class, which defines common methods and properties for all arrays. This includes instance properties such as `Length` and `Rank`, and static methods to:

- Dynamically create an array (`CreateInstance`)
- Get and set elements regardless of the array type (`GetValue/SetValue`)
- Search a sorted array (`BinarySearch`) or an unsorted array (`IndexOf`, `LastIndexOf`, `Find`, `FindIndex`, `FindLastIndex`)
- Sort an array (`Sort`)
- Copy an array (`Copy`)

### Default Element Initialization

Creating an array always preinitializes the elements with default values. The default value for a type is the result of a bitwise zeroing of memory. For example, consider creating an array of integers. Since `int` is a value type, this allocates 1,000 integers in one contiguous block of memory. The default value for each element will be 0:

```csharp
int[] a = new int[1000];
Console.Write (a[123]); // 0
```

With reference-type elements, the default value is `null`.
An array itself is always a reference-type object, regardless of element type. For instance, the following is legal:

```csharp
int[] a = null;
```

## Multidimensional Arrays

Multidimensional arrays come in two varieties: **rectangular** and **jagged**. Rectangular arrays represent an $n$-dimensional block of memory, and jagged arrays are arrays of arrays.

### Rectangular arrays

Rectangular arrays are declared using commas to separate each dimension. The following statement declares a rectangular two-dimensional array, where the dimensions are $3 \times 3$:

```csharp
int[,] matrix = new int[3, 3];
```

The `GetLength` method of an array returns the length for a given dimension (starting at 0):

```csharp
for (int i = 0; i < matrix.GetLength(0); i++)
    for (int j = 0; j < matrix.GetLength(1); j++)
        matrix[i, j] = i * 3 + j;
```

A rectangular array can be initialized as follows (to create an array identical to the previous example):

```csharp
int[,] matrix = new int[,]
{    
    {0,1,2},
    {3,4,5},
    {6,7,8}
};
```

(The code shown in boldface can be omitted in declaration statements such as this.)

### Jagged arrays

Jagged arrays are declared using successive square brackets to represent each dimension. Here is an example of declaring a jagged two-dimensional array, where the outermost dimension is 3:
int[][] matrix = new int[3][];

The inner dimensions aren’t specified in the declaration because, unlike a rectangular array, each inner array can be an arbitrary length. Each inner array is implicitly initialized to null rather than an empty array. Each inner array must be created manually:

```csharp
for (int i = 0; i < matrix.Length; i++)
{
    matrix[i] = new int[3];       // Create inner array
    for (int j = 0; j < matrix[i].Length; j++)
        matrix[i][j] = i * 3 + j;
}
```

A jagged array can be initialized as follows (to create an array identical to the previous example, but with an additional element at the end):

```csharp
int[][] matrix = new int[][]
{
    new int[] {0,1,2},
    new int[] {3,4,5},
    new int[] {6,7,8,9}
};
```

(The code shown in boldface can be omitted in declaration statements such as this.)

### Simplified Array Initialization Expressions

We’ve already seen how to simplify array initialization expressions by omitting the `new` keyword and type declaration:

```csharp
char[] vowels = new char[] {'a','e','i','o','u'};
char[] vowels =            {'a','e','i','o','u'};
```

Another approach is to omit the type name after the `new` keyword, and have the compiler infer the array type. This is a useful shortcut when passing arrays as arguments. For example, consider the following method:

```csharp
void Foo (char[] data) { ... }
```

We can call this method with an array that we create on the fly as follows:
This shortcut is essential in creating arrays of *anonymous types*, as we’ll see later.

**Variables and Parameters**

A variable represents a storage location that has a modifiable value. A variable can be a *local variable*, *parameter* (*value*, *ref*, or *out*), *field* (*instance* or *static*), or *array element*.

**The Stack and the Heap**

The stack and the heap are the places where variables and constants reside. Each has very different lifetime semantics.

**Stack**

The stack is a block of memory for storing local variables and parameters. The stack logically grows and shrinks as a function is entered and exited. Consider the following method (to avoid distraction, input argument checking is ignored):

```csharp
static int Factorial (int x)
{
    if (x == 0) return 1;
    return x * Factorial (x-1);
}
```

This method is recursive, meaning that it calls itself. Each time the method is entered, a new *int* is allocated on the stack, and each time the method exits, the *int* is deallocated.

**Heap**

The heap is a block of memory in which *objects* (i.e., reference-type instances) reside. Whenever a new object is created, it is allocated on the heap, and a reference to that object is returned. During a program’s execution, the heap starts filling up as new objects are created. The runtime has a garbage collector that periodically deallocates objects from the heap, so your com-
puter does not run out of memory. An object is eligible for deallocation as soon as it’s not referenced by anything that’s itself alive.

Value-type instances (and object references) live wherever the variable was declared. If the instance was declared as a field within an object, or as an array element, that instance lives on the heap.

NOTE
You can’t explicitly delete objects in C#, as you can in C++. An unreferenced object is eventually collected by the garbage collector.

The heap also stores static fields and constants. Unlike objects allocated on the heap (which can get garbage-collected), these live until the application domain is torn down.

Definite Assignment
C# enforces a definite assignment policy. In practice, this means that outside of an unsafe context, it’s impossible to access uninitialized memory. Definite assignment has three implications:

• Local variables must be assigned a value before they can be read.
• Function arguments must be supplied when a method is called (unless marked optional—for more information, see “Optional parameters” on page 41).
• All other variables (such as fields and array elements) are automatically initialized by the runtime.

For example, the following code results in a compile-time error:
```csharp
static void Main()
{
    int x;
}
However, if $x$ were instead a field of the containing class, this would be legal and would print 0.

**Default Values**

All type instances have a default value. The default value for the predefined types is the result of a bitwise zeroing of memory, and is `null` for reference types, 0 for numeric and enum types, '\0' for the `char` type, and `false` for the `bool` type.

You can obtain the default value for any type using the `default` keyword (in practice, this is useful with generics, as we’ll see later). The default value in a custom value type (i.e., `struct`) is the same as the default value for each field defined by the custom type.

**Parameters**

A method has a sequence of parameters. Parameters define the set of arguments that must be provided for that method. In this example, the method `Foo` has a single parameter named `p`, of type `int`:

```csharp
static void Foo (int p)   // p is a parameter
{
    ...
}
static void Main() { Foo (8); }   // 8 is an argument
```

You can control how parameters are passed with the `ref` and `out` modifiers:

<table>
<thead>
<tr>
<th>Parameter modifier</th>
<th>Passed by</th>
<th>Variable must be definitely assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>Value</td>
<td>Going in</td>
</tr>
<tr>
<td>ref</td>
<td>Reference</td>
<td>Going in</td>
</tr>
<tr>
<td>out</td>
<td>Reference</td>
<td>Going out</td>
</tr>
</tbody>
</table>
Passing arguments by value

By default, arguments in C# are passed by value, which is by far the most common case. This means a copy of the value is created when passed to the method:

```csharp
static void Foo (int p)
{
    p = p + 1;                // Increment p by 1
    Console.WriteLine (p);    // Write p to screen
}
static void Main()
{
    int x = 8;
    Foo (x);                  // Make a copy of x
    Console.WriteLine (x);    // x will still be 8
}
```

Assigning a new value does not change the contents of `x`, since `p` and `x` reside in different memory locations.

Passing a reference-type argument by value copies the reference, but not the object. In the following example, `Foo` sees the same `StringBuilder` object that `Main` instantiated, but has an independent reference to it. In other words, `sb` and `fooSB` are separate variables that reference the same `StringBuilder` object:

```csharp
static void Foo (StringBuilder fooSB)
{
    fooSB.Append ("test");
    fooSB = null;
}
static void Main()
{
    StringBuilder sb = new StringBuilder();
    Foo (sb);
    Console.WriteLine (sb.ToString());    // test
}
```

Because `fooSB` is a copy of a reference, setting it to `null` doesn’t make `sb` null. (If, however, `fooSB` was declared and called with the `ref` modifier, `sb` would become null.)
The ref modifier

To pass by reference, C# provides the ref parameter modifier. In the following example, p and x refer to the same memory locations:

```csharp
static void Foo (ref int p)
{
    p = p + 1;
    Console.WriteLine (p);
}
static void Main()
{
    int x = 8;
    Foo (ref x);           // Pass x by reference
    Console.WriteLine (x);   // x is now 9
}
```

Now assigning p a new value changes the contents of x. Notice how the ref modifier is required both when writing and when calling the method. This makes it very clear what’s going on.

---

**NOTE**

A parameter can be passed by reference or by value, regardless of whether the parameter type is a reference type or a value type.

---

The out modifier

An out argument is like a ref argument, except it:

- Need not be assigned before going into the function
- Must be assigned before it comes out of the function

The out modifier is most commonly used to get multiple return values back from a method.

The params modifier

The params modifier may be specified on the last parameter of a method so that the method accepts any number of parameters
of a particular type. The parameter type must be declared as an array. For example:

```csharp
static int Sum (params int[] ints)
{
    int sum = 0;
    for (int i = 0; i < ints.Length; i++) sum += ints[i];
    return sum;
}
```

We can call this as follows:

```csharp
Console.WriteLine (Sum (1, 2, 3, 4));    // 10
```

You can also supply a `params` argument as an ordinary array. The preceding call is semantically equivalent to:

```csharp
Console.WriteLine (new int[] { 1, 2, 3, 4 });
```

## Optional parameters

Starting with C# 4.0, methods, constructors, and indexers can declare optional parameters. A parameter is optional if it specifies a default value in its declaration:

```csharp
void Foo (int x = 23) { Console.WriteLine (x); }
```

Optional parameters may be omitted when calling the method:

```csharp
Foo();     // 23
```

The default argument of 23 is actually passed to the optional parameter x—the compiler bakes the value 23 into the compiled code at the calling side. The preceding call to `Foo` is semantically identical to:

```csharp
Foo (23);
```

because the compiler simply substitutes the default value of an optional parameter wherever it is used.

---

**WARNING**

Adding an optional parameter to a public method that’s called from another assembly requires recompilation of both assemblies—just as though the parameter were mandatory.
The default value of an optional parameter must be specified by a constant expression, or a parameterless constructor of a value type. Optional parameters cannot be marked with ref or out.

Mandatory parameters must occur before optional parameters in both the method declaration and the method call (the exception is with params arguments, which still always come last). In the following example, the explicit value of 1 is passed to x, and the default value of 0 is passed to y:

```csharp
void Foo (int x = 0, int y = 0)
{
    Console.WriteLine (x + "", " + y);
}
void Test()
{
    Foo(1); // 1, 0
}
```

To do the converse (pass a default value to x and an explicit value to y), you must combine optional parameters with named arguments.

**Named arguments**

Rather than identifying an argument by position, you can identify an argument by name. For example:

```csharp
void Foo (int x, int y)
{
    Console.WriteLine (x + ", " + y);
}
void Test()
{
    Foo (x:1, y:2); // 1, 2
}
```

Named arguments can occur in any order. The following calls to Foo are semantically identical:

```csharp
Foo (x:1, y:2);
Foo (y:2, x:1);
```

You can mix named and positional parameters, as long as the named arguments appear last:
Named arguments are particularly useful in conjunction with optional parameters. For instance, consider the following method:

```csharp
void Bar (int a=0, int b=0, int c=0, int d=0) { ... }
```

We can call this supplying only a value for `d` as follows:

```csharp
Bar (d:3);  
```

This is particularly useful when calling COM APIs.

### var—Implicitly Typed Local Variables

It is often the case that you declare and initialize a variable in one step. If the compiler is able to infer the type from the initialization expression, you can use the word `var` in place of the type declaration. For example:

```csharp
var x = "hello";
var y = new System.Text.StringBuilder();
var z = (float)Math.PI;
```

This is precisely equivalent to:

```csharp
string x = "hello";
System.Text.StringBuilder y =
    new System.Text.StringBuilder();
float z = (float)Math.PI;
```

Because of this direct equivalence, implicitly typed variables are statically typed. For example, the following generates a compile-time error:

```csharp
var x = 5;  
x = "hello";  // Compile-time error; x is of type int
```

In the section “Anonymous Types” on page 141, we describe a scenario where the use of `var` is mandatory.

### Expressions and Operators

An expression essentially denotes a value. The simplest kinds of expressions are constants (such as `123`) and variables (such as `x`).
Expressions can be transformed and combined using operators. An operator takes one or more input operands to output a new expression:

```
12 * 30  // * is an operator; 12 and 30 are operands.
```

Complex expressions can be built because an operand may itself be an expression, such as the operand \((12 * 30)\) in the following example:

```
1 + (12 * 30)
```

Operators in C# can be classed as unary, binary, or ternary—depending on the number of operands they work on (one, two, or three). The binary operators always use infix notation, where the operator is placed between the two operands.

Operators that are intrinsic to the basic plumbing of the language are called primary; an example is the method call operator. An expression that has no value is called a void expression:

```
Console.WriteLine (1)
```

Since a void expression has no value, it cannot be used as an operand to build more complex expressions:

```
1 + Console.WriteLine (1)      // Compile-time error
```

### Assignment Expressions

An assignment expression uses the = operator to assign the result of another expression to a variable. For example:

```
x = x * 5
```

An assignment expression is not a void expression. It actually carries the assignment value, and so can be incorporated into another expression. In the following example, the expression assigns 2 to \(x\) and 10 to \(y\):

```
y = 5 * (x = 2)
```

This style of expression can be used to initialize multiple values:

```
a = b = c = d = 0
```
The *compound assignment operators* are syntactic shortcuts that combine assignment with another operator. For example:

\[
\begin{align*}
    x *= 2 & \quad // \text{equivalent to } x = x * 2 \\
    x <<= 1 & \quad // \text{equivalent to } x = x << 1
\end{align*}
\]

(A subtle exception to this rule is with events, which we describe later: the += and -= operators here are treated specially and map to the event’s *add* and *remove* accessors.)

**Operator Precedence and Associativity**

When an expression contains multiple operators, *precedence* and *associativity* determine the order of their evaluation. Operators with higher precedence execute before operators of lower precedence. If the operators have the same precedence, the operator’s associativity determines the order of evaluation.

**Precedence**

The expression \(1 + 2 * 3\) is evaluated as \(1 + (2 * 3)\) because * has a higher precedence than +.

**Left-associative operators**

Binary operators (except for assignment, lambda, and null coalescing operators) are *left-associative*; in other words, they are evaluated from left to right. For example, the expression \(8/4/2\) is evaluated as \((8/4)/2\) due to left associativity. Of course, you can insert your own parentheses to change evaluation order.

**Right-associative operators**

The *assignment and lambda operators*, null coalescing operator, and (ternary) conditional operator are *right-associative*; in other words, they are evaluated from right to left. Right associativity allows multiple assignments such as \(x=y=3\) to compile: it works by first assigning \(3\) to \(y\), and then assigning the result of that expression \(3\) to \(x\).
## Operator Table

The following table lists C#’s operators in order of precedence. Operators listed under the same subheading have the same precedence. We explain user-overloadable operators in the section “Operator Overloading” on page 136.

<table>
<thead>
<tr>
<th>Operator symbol</th>
<th>Operator name</th>
<th>Example</th>
<th>Overloadable</th>
</tr>
</thead>
<tbody>
<tr>
<td>.</td>
<td>Member access</td>
<td>x.y</td>
<td>No</td>
</tr>
<tr>
<td>-&gt;</td>
<td>Pointer to struct (unsafe)</td>
<td>x-&gt;y</td>
<td>No</td>
</tr>
<tr>
<td>()</td>
<td>Function call</td>
<td>x()</td>
<td>No</td>
</tr>
<tr>
<td>[]</td>
<td>Array/index</td>
<td>a[x]</td>
<td>Via indexer</td>
</tr>
<tr>
<td>++</td>
<td>Post-increment</td>
<td>x++</td>
<td>Yes</td>
</tr>
<tr>
<td>--</td>
<td>Post-decrement</td>
<td>x--</td>
<td>Yes</td>
</tr>
<tr>
<td>new</td>
<td>Create instance</td>
<td>new Foo()</td>
<td>No</td>
</tr>
<tr>
<td>stackalloc</td>
<td>Unsafe stack allocation</td>
<td>stackalloc(10)</td>
<td>No</td>
</tr>
<tr>
<td>typeof</td>
<td>Get type from identifier</td>
<td>typeof(int)</td>
<td>No</td>
</tr>
<tr>
<td>checked</td>
<td>Integral overflow check on</td>
<td>checked(x)</td>
<td>No</td>
</tr>
<tr>
<td>unchecked</td>
<td>Integral overflow check off</td>
<td>unchecked(x)</td>
<td>No</td>
</tr>
<tr>
<td>default</td>
<td>Default value</td>
<td>default(char)</td>
<td>No</td>
</tr>
<tr>
<td>await</td>
<td>Await</td>
<td>await mytask</td>
<td>No</td>
</tr>
</tbody>
</table>

### Primary (highest precedence)

- Member access: x.y
- Pointer to struct (unsafe): x->y
- Function call: x()
- Array/index: a[x]
- Post-increment: x++
- Post-decrement: x--
- Create instance: new Foo()
<table>
<thead>
<tr>
<th>Operator symbol</th>
<th>Operator name</th>
<th>Example</th>
<th>Overloadable</th>
</tr>
</thead>
<tbody>
<tr>
<td>~</td>
<td>Bitwise complement</td>
<td>~x</td>
<td>Yes</td>
</tr>
<tr>
<td>++</td>
<td>Pre-increment</td>
<td>++x</td>
<td>Yes</td>
</tr>
<tr>
<td>--</td>
<td>Post-increment</td>
<td>--x</td>
<td>Yes</td>
</tr>
<tr>
<td>()</td>
<td>Cast</td>
<td>(int)x</td>
<td>No</td>
</tr>
<tr>
<td>*</td>
<td>Value at address (unsafe)</td>
<td>*x</td>
<td>No</td>
</tr>
<tr>
<td>&amp;</td>
<td>Address of value (unsafe)</td>
<td>&amp;x</td>
<td>No</td>
</tr>
</tbody>
</table>

**Multiplicative**

<table>
<thead>
<tr>
<th>Operator symbol</th>
<th>Operator name</th>
<th>Example</th>
<th>Overloadable</th>
</tr>
</thead>
<tbody>
<tr>
<td>*</td>
<td>Multiply</td>
<td>x * y</td>
<td>Yes</td>
</tr>
<tr>
<td>/</td>
<td>Divide</td>
<td>x / y</td>
<td>Yes</td>
</tr>
<tr>
<td>%</td>
<td>Remainder</td>
<td>x % y</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Additive**

<table>
<thead>
<tr>
<th>Operator symbol</th>
<th>Operator name</th>
<th>Example</th>
<th>Overloadable</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>Add</td>
<td>x + y</td>
<td>Yes</td>
</tr>
<tr>
<td>-</td>
<td>Subtract</td>
<td>x - y</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Shift**

<table>
<thead>
<tr>
<th>Operator symbol</th>
<th>Operator name</th>
<th>Example</th>
<th>Overloadable</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;&lt;</td>
<td>Shift left</td>
<td>x &lt;&lt; 1</td>
<td>Yes</td>
</tr>
<tr>
<td>&gt;&gt;</td>
<td>Shift right</td>
<td>x &gt;&gt; 1</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Relational**

<table>
<thead>
<tr>
<th>Operator symbol</th>
<th>Operator name</th>
<th>Example</th>
<th>Overloadable</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;</td>
<td>Less than</td>
<td>x &lt; y</td>
<td>Yes</td>
</tr>
<tr>
<td>&gt;</td>
<td>Greater than</td>
<td>x &gt; y</td>
<td>Yes</td>
</tr>
<tr>
<td>&lt;=</td>
<td>Less than or equal to</td>
<td>x &lt;= y</td>
<td>Yes</td>
</tr>
<tr>
<td>&gt;=</td>
<td>Greater than or equal to</td>
<td>x &gt;= y</td>
<td>Yes</td>
</tr>
<tr>
<td>is</td>
<td>Type is or is subclass of</td>
<td>x is y</td>
<td>No</td>
</tr>
<tr>
<td>as</td>
<td>Type conversion</td>
<td>x as y</td>
<td>No</td>
</tr>
</tbody>
</table>

**Equality**

<table>
<thead>
<tr>
<th>Operator symbol</th>
<th>Operator name</th>
<th>Example</th>
<th>Overloadable</th>
</tr>
</thead>
<tbody>
<tr>
<td>==</td>
<td>Equals</td>
<td>x == y</td>
<td>Yes</td>
</tr>
<tr>
<td>Operator symbol</td>
<td>Operator name</td>
<td>Example</td>
<td>Overloadable</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------</td>
<td>---------------</td>
<td>--------------</td>
</tr>
<tr>
<td>!=</td>
<td>Not equals</td>
<td>x != y</td>
<td>Yes</td>
</tr>
<tr>
<td>&amp;</td>
<td>And</td>
<td>x &amp; y</td>
<td>Yes</td>
</tr>
<tr>
<td>^</td>
<td>Exclusive Or</td>
<td>x ^ y</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Or</td>
<td>x</td>
</tr>
<tr>
<td>&amp;&amp;</td>
<td>Conditional And</td>
<td>x &amp;&amp; y</td>
<td>Via &amp;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Conditional Or</td>
</tr>
<tr>
<td>? :</td>
<td>Conditional</td>
<td>isTrue ? then</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>This : elseThis</td>
<td></td>
</tr>
<tr>
<td>=</td>
<td>Assign</td>
<td>x = y</td>
<td>No</td>
</tr>
<tr>
<td>*=</td>
<td>Multiply self by</td>
<td>x *= 2</td>
<td>Via *</td>
</tr>
<tr>
<td>/=</td>
<td>Divide self by</td>
<td>x /= 2</td>
<td>Via /</td>
</tr>
<tr>
<td>+=</td>
<td>Add to self</td>
<td>x += 2</td>
<td>Via +</td>
</tr>
<tr>
<td>-=</td>
<td>Subtract from self</td>
<td>x -= 2</td>
<td>Via -</td>
</tr>
<tr>
<td>&lt;&lt;=</td>
<td>Shift self left by</td>
<td>x &lt;&lt;= 2</td>
<td>Via &lt;&lt;</td>
</tr>
<tr>
<td>&gt;&gt;=</td>
<td>Shift self right by</td>
<td>x &gt;&gt;= 2</td>
<td>Via &gt;&gt;</td>
</tr>
<tr>
<td>&amp;=</td>
<td>And self by</td>
<td>x &amp;= 2</td>
<td>Via &amp;</td>
</tr>
<tr>
<td>^=</td>
<td>Exclusive-Or self by</td>
<td>x ^= 2</td>
<td>Via ^</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Or self by</td>
<td>x</td>
</tr>
<tr>
<td>=&gt;</td>
<td>Lambda</td>
<td>x =&gt; x + 1</td>
<td>No</td>
</tr>
</tbody>
</table>
Statements

Functions comprise statements that execute sequentially in the textual order in which they appear. A statement block is a series of statements appearing between braces (the {} tokens).

Declaration Statements

A declaration statement declares a new variable, optionally initializing the variable with an expression. A declaration statement ends in a semicolon. You may declare multiple variables of the same type in a comma-separated list. For example:

```cpp
bool rich = true, famous = false;
```

A constant declaration is like a variable declaration, except that it cannot be changed after it has been declared, and the initialization must occur with the declaration (more on this in “Constants” on page 68):

```cpp
const double c = 2.99792458E08;
```

Local variable scope

The scope of a local variable or local constant variable extends throughout the current block. You cannot declare another local variable with the same name in the current block or in any nested blocks.

Expression Statements

Expression statements are expressions that are also valid statements. In practice, this means expressions that “do” something; in other words, expressions that:

- Assign or modify a variable
- Instantiate an object
- Call a method

Expressions that do none of these are not valid statements:
string s = "foo";
s.Length; // Illegal statement: does nothing!

When you call a constructor or a method that returns a value, you’re not obliged to use the result. However, unless the constructor or method changes state, the statement is useless:

    new StringBuilder(); // Legal, but useless
    x.Equals (y); // Legal, but useless

Selection Statements

Selection statements conditionally control the flow of program execution.

The if statement

An if statement executes a statement if a bool expression is true. For example:

    if (5 < 2 * 3)
        Console.WriteLine ("true"); // true

The statement can be a code block:

    if (5 < 2 * 3)
    {
        Console.WriteLine ("true"); // true
        Console.WriteLine ("...")
    }

The else clause

An if statement can optionally feature an else clause:

    if (2 + 2 == 5)
        Console.WriteLine ("Does not compute");
    else
        Console.WriteLine ("False"); // False

Within an else clause, you can nest another if statement:

    if (2 + 2 == 5)
        Console.WriteLine ("Does not compute");
    else
        if (2 + 2 == 4)
            Console.WriteLine ("Comptes"); // Computes
Changing the flow of execution with braces

An `else` clause always applies to the immediately preceding `if` statement in the statement block. For example:

```csharp
if (true)
    if (false)
        Console.WriteLine();
    else
        Console.WriteLine ("executes");
```

This is semantically identical to:

```csharp
if (true)
{
    if (false)
        Console.WriteLine();
    else
        Console.WriteLine ("executes");
}
```

We can change the execution flow by moving the braces:

```csharp
if (true)
{
    if (false)
        Console.WriteLine();
}
else
    Console.WriteLine ("does not execute");
```

C# has no “elseif” keyword; however, the following pattern achieves the same result:

```csharp
static void TellMeWhatICanDo (int age)
{
    if (age >= 35)
        Console.WriteLine ("You can be president!");
    else if (age >= 21)
        Console.WriteLine ("You can drink!");
    else if (age >= 18)
        Console.WriteLine ("You can vote!");
    else
        Console.WriteLine ("You can wait");
}
```
The switch statement

Switch statements let you branch program execution based on a selection of possible values that a variable may have. Switch statements may result in cleaner code than multiple if statements, since switch statements require an expression to be evaluated only once. For instance:

```csharp
static void ShowCard (int cardNumber)
{
    switch (cardNumber)
    {
        case 13:
            Console.WriteLine ("King");
            break;
        case 12:
            Console.WriteLine ("Queen");
            break;
        case 11:
            Console.WriteLine ("Jack");
            break;
        default:    // Any other cardNumber
            Console.WriteLine (cardNumber);
            break;
    }
}
```

You can only switch on an expression of a type that can be statically evaluated, which restricts it to the string type, the built-in integral types, the enum types, and nullable versions of these (see “Nullable Types” on page 132). At the end of each case clause, you must say explicitly where execution is to go next, with some kind of jump statement. Here are the options:

- **break** (jumps to the end of the switch statement)
- **goto case x** (jumps to another case clause)
- **goto default** (jumps to the default clause)
- Any other jump statement—specifically, return, throw, continue, or goto label

When more than one value should execute the same code, you can list the common cases sequentially:
```
switch (cardNumber)
{
    case 13:
    case 12:
    case 11:
        Console.WriteLine("Face card");
        break;
    default:
        Console.WriteLine("Plain card");
        break;
}
```

This feature of a `switch` statement can be pivotal in terms of producing cleaner code than multiple `if-else` statements.

**Iteration Statements**

C# enables a sequence of statements to execute repeatedly with the `while`, `do-while`, `for`, and `foreach` statements.

**while and do-while loops**

`while` loops repeatedly execute a body of code while a `bool` expression is true. The expression is tested _before_ the body of the loop is executed. For example, the following writes `012`:

```csharp
int i = 0;
while (i < 3)
{
    Console.Write (i++); // Braces here are optional
}
```

do-while loops differ in functionality from `while` loops only in that they test the expression _after_ the statement block has executed (ensuring that the block is always executed at least once). Here’s the preceding example rewritten with a `do-while` loop:

```csharp
int i = 0;
do
{
    Console.WriteLine (i++);
} while (i < 3);
```
for loops

for loops are like while loops with special clauses for initialization and iteration of a loop variable. A for loop contains three clauses as follows:

\[
\text{for (init-clause; condition-clause; iteration-clause)} \\
\quad \text{statement-or-statement-block}
\]

The init-clause executes before the loop begins, and typically initializes one or more iteration variables.

The condition-clause is a bool expression which is tested before each loop iteration. The body executes while this condition is true.

The iteration-clause is executed after each iteration of the body. It’s typically used to update the iteration variable.

For example, the following prints the numbers 0 through 2:

```csharp
for (int i = 0; i < 3; i++)
    Console.WriteLine (i);
```

The following prints the first 10 Fibonacci numbers (where each number is the sum of the previous two):

```csharp
for (int i = 0, prevFib = 1, curFib = 1; i < 10; i++)
{
    Console.WriteLine (prevFib);
    int newFib = prevFib + curFib;
    prevFib = curFib; curFib = newFib;
}
```

Any of the three parts of the for statement may be omitted. One can implement an infinite loop such as the following (though while(true) may be used instead):

```csharp
for (;;) Console.WriteLine ("interrupt me");
```

default loops

The foreach statement iterates over each element in an enumerable object. Most of the types in C# and the .NET Framework that represent a set or list of elements are enumerable. For example, both an array and a string are enumerable. Here
is an example of enumerating over the characters in a string, from the first character through to the last:

```csharp
foreach (char c in "beer")
    Console.WriteLine (c + " ");  // b e e r
```

We define enumerable objects in “Enumeration and Iterators” on page 126.

**Jump Statements**

The C# jump statements are **break**, **continue**, **goto**, **return**, and **throw**. We cover the **throw** keyword in “try Statements and Exceptions” on page 118.

**The break statement**

The **break** statement ends the execution of the body of an iteration or **switch** statement:

```csharp
int x = 0;
while (true)
{
    if (x++ > 5) break;  // break from the loop
}
// execution continues here after break
...
```

**The continue statement**

The **continue** statement forgoes the remaining statements in the loop and makes an early start on the next iteration. The following loop skips even numbers:

```csharp
for (int i = 0; i < 10; i++)
{
    if ((i % 2) == 0) continue;
    Console.Write (i + " ");  // 1 3 5 7 9
}
```

**The goto statement**

The **goto** statement transfers execution to a label (denoted with a colon suffix) within a statement block. The following iterates the numbers 1 through 5, mimicking a **for** loop:
int i = 1;
startLoop:
if (i <= 5)
{
    Console.Write (i + " ");  // 1 2 3 4 5
    i++;
    goto startLoop;
}

The return statement

The return statement exits the method and must return an expression of the method’s return type if the method is nonvoid:

    static decimal AsPercentage (decimal d)
    {
        decimal p = d * 100m;
        return p;     // Return to calling method with value
    }

A return statement can appear anywhere in a method (except in a finally block).

Namespaces

A namespace is a domain within which type names must be unique. Types are typically organized into hierarchical namespaces—both to avoid naming conflicts and to make type names easier to find. For example, the RSA type that handles public key encryption is defined within the following namespace:

    System.Security.Cryptography

A namespace forms an integral part of a type’s name. The following code calls RSA’s Create method:

        System.Security.Cryptography.RSA.Create();
NOTE

Namespaces are independent of assemblies, which are units of deployment such as an .exe or .dll.

Namespaces also have no impact on member accessibility—public, internal, private, and so on.

The namespace keyword defines a namespace for types within that block. For example:

```csharp
namespace Outer.Middle.Inner
{
    class Class1 {}
    class Class2 {}
}
```

The dots in the namespace indicate a hierarchy of nested namespaces. The code that follows is semantically identical to the preceding example.

```csharp
namespace Outer
{
    namespace Middle
    {
        namespace Inner
        {
            class Class1 {}
            class Class2 {}
        }
    }
}
```

You can refer to a type with its fully qualified name, which includes all namespaces from the outermost to the innermost. For example, we could refer to Class1 in the preceding example as Outer.Middle.Inner.Class1.

Types not defined in any namespace are said to reside in the global namespace. The global namespace also includes top-level namespaces, such as Outer in our example.
The using Directive

The using directive imports a namespace and is a convenient way to refer to types without their fully qualified names. For example, we can refer to Class1 in the preceding example as follows:

```csharp
using Outer.Middle.Inner;

class Test       // Test is in the global namespace
{
    static void Main()
    {
        Class1 c;     // Don't need fully qualified name
        ...
    }
}
```

A using directive can be nested within a namespace itself, to limit the scope of the directive.

Rules Within a Namespace

Name scoping

Names declared in outer namespaces can be used unqualified within inner namespaces. In this example, Class1 does not need qualification within Inner:

```csharp
namespace Outer
{
    class Class1 {}

    namespace Inner
    {
        class Class2 : Class1 {}
    }
}
```

If you want to refer to a type in a different branch of your namespace hierarchy, you can use a partially qualified name. In the following example, we base SalesReport on Common.ReportBase:
namespace MyTradingCompany
{
    namespace Common
    {
        class ReportBase {}
    }
    namespace ManagementReporting
    {
        class SalesReport : Common.ReportBase {}
    }
}

Name hiding

If the same type name appears in both an inner and an outer namespace, the inner name wins. To refer to the type in the outer namespace, you must qualify its name.

---

**NOTE**

All type names are converted to fully qualified names at compile time. Intermediate Language (IL) code contains no unqualified or partially qualified names.

---

Repeated namespaces

You can repeat a namespace declaration, as long as the type names within the namespaces don’t conflict:

```csharp
namespace Outer.Middle.Inner { class Class1 {} }
namespace Outer.Middle.Inner { class Class2 {} }
```

The classes can even span source files and assemblies.

**The global:: qualifier**

Occasionally, a fully qualified type name may conflict with an inner name. You can force C# to use the fully qualified type name by prefixing it with `global::` as follows:

```csharp
global::System.Text.StringBuilder sb;
```
Aliasing Types and Namespaces

Importing a namespace can result in type-name collision. Rather than importing the whole namespace, you can import just the specific types you need, giving each type an alias. For example:

```csharp
using PropertyInfo2 = System.Reflection.PropertyInfo;
class Program { PropertyInfo2 p; }
```

An entire namespace can be aliased, as follows:

```csharp
using R = System.Reflection;
class Program { R.PropertyInfo p; }
```

Classes

A class is the most common kind of reference type. The simplest possible class declaration is as follows:

```csharp
class Foo
{
}
```

A more complex class optionally has the following:

- **Preceding the keyword class**
  - **Attributes and class modifiers**. The non-nested class modifiers are public, internal, abstract, sealed, static, unsafe, and partial.

- **Following YourClassName**
  - **Generic type parameters, a base class, and interfaces**

- **Within the braces**
  - **Class members** (these are methods, properties, indexers, events, fields, constructors, overloaded operators, nested types, and a finalizer)

Fields

A field is a variable that is a member of a class or struct. For example:

```csharp
class Octopus
{
    string name;
}
A field may have the `readonly` modifier to prevent it from being modified after construction. A read-only field can be assigned only in its declaration or within the enclosing type’s constructor.

Field initialization is optional. An uninitialized field has a default value (0, \0, `null`, `false`). Field initializers run before constructors, in the order in which they appear.

For convenience, you may declare multiple fields of the same type in a comma-separated list. This is a convenient way for all the fields to share the same attributes and field modifiers. For example:

```csharp
static readonly int legs = 8, eyes = 2;
```

**Methods**

A method performs an action in a series of statements. A method can receive input data from the caller by specifying parameters and output data back to the caller by specifying a return type. A method can specify a `void` return type, indicating that it doesn’t return any value to its caller. A method can also output data back to the caller via `ref` and `out` parameters.

A method’s signature must be unique within the type. A method’s signature comprises its name and parameter types (but not the parameter names, nor the return type).

**Overloading methods**

A type may overload methods (have multiple methods with the same name), as long as the parameter types are different. For example, the following methods can all coexist in the same type:

```csharp
void Foo (int x);
void Foo (double x);
void Foo (int x, float y);
void Foo (float x, int y);
```
Instance Constructors

Constructors run initialization code on a class or struct. A constructor is defined like a method, except that the method name and return type are reduced to the name of the enclosing type:

```csharp
public class Panda
{
    string name;              // Define field

    public Panda (string n)   // Define constructor
    {
        name = n;               // Initialization code
    }
}
...
Panda p = new Panda ("Petey");   // Call constructor
```

A class or struct may overload constructors. One overload may call another, using the `this` keyword:

```csharp
public class Wine
{
    public Wine (decimal price) {...}

    public Wine (decimal price, int year)
        : this (price) {...}
}
```

When one constructor calls another, the called constructor executes first.

You can pass an `expression` into another constructor as follows:

```csharp
public Wine (decimal price, DateTime year)
    : this (price, year.Year) {...}
```

The expression itself cannot make use of the `this` reference, for example, to call an instance method. It can, however, call static methods.

**Implicit parameterless constructors**

For classes, the C# compiler automatically generates a parameterless public constructor if and only if you do not define any constructors. However, as soon as you define at least one con-
structor, the parameterless constructor is no longer automatically generated.

For structs, a parameterless constructor is intrinsic to the struct; therefore, you cannot define your own. The role of a struct’s implicit parameterless constructor is to initialize each field with default values.

**Nonpublic constructors**

Constructors do not need to be public. A common reason to have a nonpublic constructor is to control instance creation via a static method call. The static method could be used to return an object from a pool rather than creating a new object, or return a specialized subclass chosen based on input arguments.

**Object Initializers**

To simplify object initialization, the accessible fields or properties of an object can be initialized via an *object initializer* directly after construction. For example, consider the following class:

```csharp
public class Bunny
{
    public string Name;
    public bool LikesCarrots, LikesHumans;

    public Bunny () {}
    public Bunny (string n) { Name = n; }
}
```

Using object initializers, you can instantiate `Bunny` objects as follows:

```csharp
Bunny b1 = new Bunny {
    Name="Bo",
    LikesCarrots = true,
    LikesHumans = false
};
```
Bunny b2 = new Bunny ("Bo") {
    LikesCarrots = true,
    LikesHumans = false
};

The this Reference

The this reference refers to the instance itself. In the following example, the Marry method uses this to set the partner’s mate field:

```csharp
public class Panda {
    public Panda Mate;

    public void Marry (Panda partner) {
        Mate = partner;
        partner.Mate = this;
    }
}
```

The this reference also disambiguates a local variable or parameter from a field. For example:

```csharp
public class Test {
    string name;
    public Test (string name) { this.name = name; }
}
```

The this reference is valid only within nonstatic members of a class or struct.

Properties

Properties look like fields from the outside, but internally they contain logic, like methods do. For example, you can’t tell by looking at the following code whether CurrentPrice is a field or a property:

```csharp
Stock msft = new Stock();
msft.CurrentPrice = 30;
```
msft.CurrentPrice -= 3;
Console.WriteLine (msft.CurrentPrice);

A property is declared like a field, but with a get/set block added. Here’s how to implement CurrentPrice as a property:

```csharp
public class Stock
{
    decimal currentPrice;  // The private "backing" field

    public decimal CurrentPrice    // The public property
    {
        get { return currentPrice; }
        set { currentPrice = value; }
    }
}
```

get and set denote property *accessors*. The get accessor runs when the property is read. It must return a value of the property’s type. The set accessor runs when the property is assigned. It has an implicit parameter named value of the property’s type that you typically assign to a private field (in this case, currentPrice).

Although properties are accessed in the same way as fields, they differ in that they give the implementer complete control over getting and setting its value. This control enables the implementer to choose whatever internal representation is needed, without exposing the internal details to the user of the property. In this example, the set method could throw an exception if value was outside a valid range of values.

---

**NOTE**

Throughout this book, we use public fields to keep the examples free of distraction. In a real application, you would typically favor public properties over public fields to promote encapsulation.

---

A property is read-only if it specifies only a get accessor, and it is write-only if it specifies only a set accessor. Write-only properties are rarely used. A property typically has a dedicated
backing field to store the underlying data. However, it need not—it may instead return a value computed from other data.

**Automatic properties**

The most common implementation for a property is a getter and/or setter that simply reads and writes to a private field of the same type as the property. An *automatic property* declaration instructs the compiler to provide this implementation. We can redeclare the first example in this section as follows:

```csharp
public class Stock
{
    public decimal CurrentPrice { get; set; }
}
```

The compiler automatically generates a private backing field of a compiler-generated name that cannot be referred to. The *set* accessor can be marked `private` if you want to expose the property as read-only to other types.

**get and set accessibility**

The *get* and *set* accessors can have different access levels. The typical use case for this is to have a `public` property with an `internal` or `private` access modifier on the setter:

```csharp
private decimal x;
public decimal X
{
    get { return x; }
    private set { x = Math.Round(value, 2); }
}
```

Notice that you declare the property itself with the more permissive access level (`public`, in this case), and add the modifier to the accessor you want to be less accessible.

**Indexers**

Indexers provide a natural syntax for accessing elements in a class or struct that encapsulate a list or dictionary of values. Indexers are similar to properties, but are accessed via an index.
argument rather than a property name. The `string` class has an indexer that lets you access each of its `char` values via an `int` index:

```csharp
string s = "hello";
Console.WriteLine(s[0]); // 'h'
Console.WriteLine(s[3]); // 'l'
```

The syntax for using indexers is like that for using arrays, except that the index argument(s) can be of any type(s).

**Implementing an indexer**

To write an indexer, define a property called `this`, specifying the arguments in square brackets. For instance:

```csharp
class Sentence
{
    string[] words = "The quick brown fox".Split();

    public string this [int wordNum]       // indexer
    {
        get { return words [wordNum];  }
        set { words [wordNum] = value; }
    }
}
```

Here’s how we could use this indexer:

```csharp
Sentence s = new Sentence();
Console.WriteLine(s[3]);       // fox
s[3] = "kangaroo";
Console.WriteLine(s[3]);       // kangaroo
```

A type may declare multiple indexers, each with parameters of different types. An indexer can also take more than one parameter:

```csharp
public string this [int arg1, string arg2]
{
    get { ... } set { ... }
}
```

If you omit the `set` accessor, an indexer becomes read-only.
Constants

A constant is a static field whose value can never change. A constant is evaluated statically at compile time and the compiler literally substitutes its value whenever used (rather like a macro in C++). A constant can be any of the built-in numeric types, bool, char, string, or an enum type.

A constant is declared with the const keyword and must be initialized with a value. For example:

```csharp
public class Test
{
    public const string Message = "Hello World";
}
```

A constant is much more restrictive than a static readonly field—both in the types you can use and in field initialization semantics. A constant also differs from a static readonly field in that the evaluation of the constant occurs at compile time. Constants can also be declared local to a method:

```csharp
static void Main()
{
    const double twoPI = 2 * System.Math.PI;
...
}
```

Static Constructors

A static constructor executes once per type, rather than once per instance. A type can define only one static constructor, and it must be parameterless and have the same name as the type:

```csharp
class Test
{
    static Test() { Console.Write ("Type Initialized"); }
}
```

The runtime automatically invokes a static constructor just prior to the type being used. Two things trigger this: instantiating the type, and accessing a static member in the type.
WARNING
If a static constructor throws an unhandled exception, that type becomes unusable for the life of the application.

Static field initializers run just before the static constructor is called. If a type has no static constructor, field initializers will execute just prior to the type being used—or anytime earlier at the whim of the runtime. (This means that the presence of a static constructor may cause field initializers to execute later in the program than they would otherwise.)

Static Classes
A class can be marked static, indicating that it must be composed solely of static members and cannot be subclassed. The System.Console and System.Math classes are good examples of static classes.

Finalizers
Finalizers are class-only methods that execute before the garbage collector reclaims the memory for an unreferenced object. The syntax for a finalizer is the name of the class prefixed with the ~ symbol:

```csharp
class Class1
{
    ~Class1() { ... }
}
```

C# translates a finalizer into a method that overrides the Finalize method in the object class. We discuss garbage collection and finalizers fully in Chapter 12 of C# 5.0 in a Nutshell.

Partial Types and Methods
Partial types allow a type definition to be split—typically across multiple files. A common scenario is for a partial class to be
auto-generated from some other source (e.g., a Visual Studio template), and for that class to be augmented with additional hand-authored methods. For example:

```
// PaymentFormGen.cs - auto-generated
partial class PaymentForm { ... }
```

```
// PaymentForm.cs - hand-authored
partial class PaymentForm { ... }
```

Each participant must have the partial declaration.

Participants cannot have conflicting members. A constructor with the same parameters, for instance, cannot be repeated. Partial types are resolved entirely by the compiler, which means that each participant must be available at compile time and must reside in the same assembly.

A base class may be specified on a single participant or on all participants. In addition, each participant can independently specify interfaces to implement. We cover base classes and interfaces in more detail in the sections “Inheritance” on page 71 and “Interfaces” on page 86.

**Partial methods**

A partial type may contain partial methods. These let an auto-generated partial type provide customizable hooks for manual authoring. For example:

```
partial class PaymentForm    // In auto-generated file
{
    partial void ValidatePayment (decimal amount);
}
```

```
partial class PaymentForm    // In hand-authored file
{
    partial void ValidatePayment (decimal amount)
    {
        if (amount > 100) Console.Write ("Expensive!");
    }
}
```

A partial method consists of two parts: a definition and an implementation. The definition is typically written by a code
generator, and the implementation is typically manually authored. If an implementation is not provided, the definition of the partial method is compiled away (as is the code that calls it). This allows auto-generated code to be liberal in providing hooks, without having to worry about bloat. Partial methods must be `void` and are implicitly `private`.

**Inheritance**

A class can *inherit* from another class to extend or customize the original class. Inheriting from a class lets you reuse the functionality in that class instead of building it from scratch. A class can inherit from only a single class, but can itself be inherited by many classes, thus forming a class hierarchy. In this example, we start by defining a class called `Asset`:

```csharp
public class Asset { public string Name; }
```

Next, we define classes called `Stock` and `House`, which will inherit from `Asset`. `Stock` and `House` get everything an `Asset` has, plus any additional members that they define:

```csharp
public class Stock : Asset // inherits from Asset
{
    public long SharesOwned;
}

public class House : Asset // inherits from Asset
{
    public decimal Mortgage;
}
```

Here’s how we can use these classes:

```csharp
Stock msft = new Stock { Name="MSFT",
                           SharesOwned=1000 };

Console.WriteLine (msft.Name);         // MSFT
Console.WriteLine (msft.SharesOwned);  // 1000

House mansion = new House { Name="Mansion",
                           Mortgage=250000 };
```

Inheritance | 71
The subclasses, Stock and House, inherit the Name property from the base class, Asset.

Subclasses are also called derived classes.

### Polymorphism

References are polymorphic. This means a variable of type \( x \) can refer to an object that subclasses \( x \). For instance, consider the following method:

```csharp
public static void Display (Asset asset)
{
    System.Console.WriteLine (asset.Name);
}
```

This method can display both a Stock and a House, since they are both Assets. Polymorphism works on the basis that subclasses (Stock and House) have all the features of their base class (Asset). The converse, however, is not true. If Display was re-written to accept a House, you could not pass in an Asset.

### Casting and Reference Conversions

An object reference can be:

- Implicitly *upcast* to a base class reference
- Explicitly *downcast* to a subclass reference

Upcasting and downcasting between compatible reference types performs *reference conversions*: a new reference is created that points to the *same* object. An upcast always succeeds; a downcast succeeds only if the object is suitably typed.

#### Upcasting

An upcast operation creates a base class reference from a subclass reference. For example:

```csharp
Stock msft = new Stock();    // From previous example
Asset a = msft;              // Upcast
```
After the upcast, variable \( a \) still references the same \( \text{Stock} \) object as variable \( \text{msft} \). The object being referenced is not itself altered or converted:

\[
\text{Console.WriteLine} (a == \text{msft}); \quad \text{// True}
\]

Although \( a \) and \( \text{msft} \) refer to the same object, \( a \) has a more restrictive view on that object:

\[
\begin{align*}
\text{Console.WriteLine} (a.\text{Name}); & \quad \text{// OK} \\
\text{Console.WriteLine} (a.\text{SharesOwned}); & \quad \text{// Error}
\end{align*}
\]

The last line generates a compile-time error because the variable \( a \) is of type \( \text{Asset} \), even though it refers to an object of type \( \text{Stock} \). To get to its \( \text{SharesOwned} \) field, you must \textit{downcast} the \( \text{Asset} \) to a \( \text{Stock} \).

**Downcasting**

A downcast operation creates a subclass reference from a base class reference. For example:

```csharp
Stock \text{msft} = \text{new Stock}();
Asset \text{a} = \text{msft}; \quad \text{// Upcast}
\text{Stock} \text{s} = (\text{Stock})a; \quad \text{// Downcast}
\text{Console.WriteLine} (s.\text{SharesOwned}); \quad \text{// <No error>}
\text{Console.WriteLine} (s == a); \quad \text{// True}
\text{Console.WriteLine} (s == \text{msft}); \quad \text{// True}
```

As with an upcast, only references are affected—not the underlying object. A downcast requires an explicit cast because it can potentially fail at runtime:

```csharp
\text{House} \text{h} = \text{new House}();
\text{Asset} \text{a} = \text{h}; \quad \text{// Upcast always succeeds}
\text{Stock} \text{s} = (\text{Stock})a; \quad \text{// Downcast fails: a is not a Stock}
```

If a downcast fails, an \texttt{InvalidCastException} is thrown. This is an example of \textit{runtime type checking} (see “Static and Runtime Type Checking” on page 81).

**The as operator**

The \texttt{as} operator performs a downcast that evaluates to \texttt{null} (rather than throwing an exception) if the downcast fails:
Asset a = new Asset();
Stock s = a as Stock; // s is null; no exception thrown

This is useful when you’re going to subsequently test whether the result is null:

    if (s != null) Console.WriteLine(s.SharesOwned);

The as operator cannot perform custom conversions (see the section “Operator Overloading” on page 136) and it cannot do numeric conversions.

**The is operator**

The is operator tests whether a reference conversion would succeed; in other words, whether an object derives from a specified class (or implements an interface). It is often used to test before downcasting:

    if (a is Stock) Console.WriteLine(((Stock)a).SharesOwned);

The is operator does not consider custom or numeric conversions, but it does consider unboxing conversions (see “The object Type” on page 79).

**Virtual Function Members**

A function marked as virtual can be overridden by subclasses wanting to provide a specialized implementation. Methods, properties, indexers, and events can all be declared virtual:

    public class Asset
    {
        public string Name;
        public virtual decimal Liability { get { return 0; } }
    }

A subclass overrides a virtual method by applying the override modifier:

    public class House : Asset
    {
        public decimal Mortgage;

        public override decimal Liability
By default, the Liability of an Asset is 0. A Stock does not need to specialize this behavior. However, the House specializes the Liability property to return the value of the Mortgage:

```csharp
House mansion = new House { Name="Mansion", Mortgage=250000 };  
Asset a = mansion;  
Console.WriteLine (mansion.Liability);  // 250000  
Console.WriteLine (a.Liability);        // 250000
```

The signatures, return types, and accessibility of the virtual and overridden methods must be identical. An overridden method can call its base class implementation via the base keyword (see “The base Keyword” on page 76).

**Abstract Classes and Abstract Members**

A class declared as `abstract` can never be instantiated. Instead, only its concrete subclasses can be instantiated.

Abstract classes are able to define `abstract members`, which are like virtual members, except they don’t provide a default implementation. That implementation must be provided by the subclass, unless that subclass is also declared abstract:

```csharp
public abstract class Asset
{
    // Note empty implementation
    public abstract decimal NetValue { get; }
}
```

Subclasses override abstract members just as though they were virtual.

**Hiding Inherited Members**

A base class and a subclass may define identical members. For example:

```csharp
public class A       { public int Counter = 1;  }
public class B : A  { public int Counter = 2;  }
```
The Counter field in class B is said to *hide* the Counter field in class A. Usually, this happens by accident, when a member is added to the base type *after* an identical member was added to the subtype. For this reason, the compiler generates a warning, and then resolves the ambiguity as follows:

- References to A (at compile time) bind to A.Counter.
- References to B (at compile time) bind to B.Counter.

Occasionally, you want to hide a member deliberately, in which case you can apply the `new` modifier to the member in the subclass. The `new` modifier *does nothing more than suppress the compiler warning that would otherwise result*:

```
public class A     { public     int Counter = 1; }
public class B : A { public new int Counter = 2; }
```

The `new` modifier communicates your intent to the compiler—and other programmers—that the duplicate member is not an accident.

### Sealing Functions and Classes

An overridden function member may *seal* its implementation with the `sealed` keyword to prevent it from being overridden by further subclasses. In our earlier virtual function member example, we could have sealed House’s implementation of Liability, preventing a class that derives from House from overriding Liability, as follows:

```
public sealed override decimal Liability { get { ... } }
```

You can also seal the class itself, implicitly sealing all the virtual functions, by applying the `sealed` modifier to the class itself.

### The base Keyword

The `base` keyword is similar to the `this` keyword. It serves two essential purposes: accessing an overridden function member from the subclass, and calling a base-class constructor (see the next section).
In this example, House uses the base keyword to access Asset’s implementation of Liability:

```csharp
public class House : Asset
{
    ...
    public override decimal Liability
    {
        get { return base.Liability + Mortgage; }
    }
}
```

With the base keyword, we access Asset’s Liability property nonvirtually. This means we will always access Asset’s version of this property—regardless of the instance’s actual runtime type.

The same approach works if Liability is hidden rather than overridden. (You can also access hidden members by casting to the base class before invoking the function.)

## Constructors and Inheritance

A subclass must declare its own constructors. For example, if we define `Baseclass` and `Subclass` as follows:

```csharp
public class Baseclass
{
    public int X;
    public Baseclass () { }
    public Baseclass (int x) { this.X = x; }
}
public class Subclass : Baseclass { }
```

the following is illegal:

```csharp
Subclass s = new Subclass (123);
```

Subclass must “redefine” any constructors it wants to expose. In doing so, it can call any of the base class’s constructors with the base keyword:

```csharp
public class Subclass : Baseclass
{
    public Subclass (int x) : base (x) { ... }
}
```
The `base` keyword works rather like the `this` keyword, except that it calls a constructor in the base class. Base-class constructors always execute first; this ensures that `base` initialization occurs before `specialized` initialization.

If a constructor in a subclass omits the `base` keyword, the base type’s `parameterless` constructor is implicitly called (if the base class has no accessible parameterless constructor, the compiler generates an error).

**Constructor and field initialization order**

When an object is instantiated, initialization takes place in the following order:

1. From subclass to base class:
   a. Fields are initialized.
   b. Arguments to base-class constructor calls are evaluated.
2. From base class to subclass:
   a. Constructor bodies execute.

**Overloading and Resolution**

Inheritance has an interesting impact on method overloading. Consider the following two overloads:

```csharp
static void Foo (Asset a) { }
static void Foo (House h) { }
```

When an overload is called, the most specific type has precedence:

```csharp
House h = new House (...);
Foo(h);                      // Calls Foo(House)
```

The particular overload to call is determined statically (at compile time) rather than at runtime. The following code calls `Foo(Asset)`, even though the runtime type of `a` is `House`:

```csharp
Asset a = new House (...);
Foo(a);                      // Calls Foo(Asset)
```
NOTE

If you cast Asset to dynamic (see “Dynamic Binding” on page 166), the decision as to which overload to call is deferred until runtime and is based on the object’s actual type.

The object Type

object (System.Object) is the ultimate base class for all types. Any type can be implicitly upcast to object.

To illustrate how this is useful, consider a general-purpose stack. A stack is a data structure based on the principle of “last in, first out” (LIFO). A stack has two operations: push an object on the stack, and pop an object off the stack. Here is a simple implementation that can hold up to 10 objects:

```csharp
public class Stack
{
    int position;
    object[] data = new object[10];
    public void Push (object o) { data[position++] = o; }
    public object Pop() { return data[--position]; }
}
```

Because Stack works with the object type, we can Push and Pop instances of any type to and from the Stack:

```csharp
Stack stack = new Stack();
stack.Push ("sausage");
string s = (string) stack.Pop(); // Downcast
Console.WriteLine (s); // sausage
```

object is a reference type, by virtue of being a class. Despite this, value types, such as int, can also be cast to and from object. To make this possible, the CLR must perform some special work to bridge the underlying differences between value and reference types. This process is called boxing and unboxing.
NOTE
In the section “Generics” on page 93, we’ll describe how to improve our Stack class to better handle stacks with same-typed elements.

Boxing and Unboxing
Boxing is the act of casting a value-type instance to a reference-type instance. The reference type may be either the object class or an interface (see “Interfaces” on page 86). In this example, we box an int into an object:

```csharp
int x = 9;
object obj = x;       // Box the int
```

Unboxing reverses the operation, by casting the object back to the original value type:

```csharp
int y = (int)obj;      // Unbox the int
```

Unboxing requires an explicit cast. The runtime checks that the stated value type matches the actual object type, and throws an InvalidCastException if the check fails. For instance, the following throws an exception, because long does not exactly match int:

```csharp
object obj = 9;       // 9 is inferred to be of type int
long x = (long) obj;  // InvalidCastException
```

The following succeeds, however:

```csharp
object obj = 9;
long x = (int) obj;
```

As does this:

```csharp
object obj = 3.5;      // 3.5 inferred to be type double
int x = (int) (double) obj; // x is now 3
```

In the last example, (double) performs an unboxing and then (int) performs a numeric conversion.
Boxing copies the value-type instance into the new object, and unboxing copies the contents of the object back into a value-type instance:

```csharp
int i = 3;
object boxed = i;
i = 5;
Console.WriteLine (boxed);    // 3
```

### Static and Runtime Type Checking

C# checks types both statically (at compile time) and at runtime.

Static type checking enables the compiler to verify the correctness of your program without running it. The following code will fail because the compiler enforces static typing:

```csharp
int x = "5";
```

Runtime type checking is performed by the CLR when you downcast via a reference conversion or unboxing:

```csharp
object y = "5";
int z = (int) y;       // Runtime error, downcast failed
```

Runtime type checking is possible because each object on the heap internally stores a little type token. This token can be retrieved by calling the `GetType` method of `object`.

### The `GetType` Method and `typeof` Operator

All types in C# are represented at runtime with an instance of `System.Type`. There are two basic ways to get a `System.Type` object: call `GetType` on the instance, or use the `typeof` operator on a type name. `GetType` is evaluated at runtime; `typeof` is evaluated statically at compile time.

`System.Type` has properties for such things as the type’s name, assembly, base type, and so on. For example:

```csharp
int x = 3;

Console.Write (x.GetType().Name);               // Int32
```
System.Type also has methods that act as a gateway to the runtime’s reflection model. For detailed information, see Chapter 19 of *C# 5.0 in a Nutshell*.

**Object Member Listing**

Here are all the members of object:

- public extern Type GetType();
- public virtual bool Equals (object obj);
- public static bool Equals (object objA, object objB);
- public static bool ReferenceEquals (object objA, object objB);
- public virtual int GetHashCode();
- public virtual string ToString();
- protected override void Finalize();
- protected extern object MemberwiseClone();

**Equals, ReferenceEquals, and GetHashCode**

The `Equals` method in the `object` class is similar to the `==` operator, except that `Equals` is virtual, whereas `==` is static. The following example illustrates the difference:

```csharp
object x = 3;
object y = 3;
Console.WriteLine (x == y);        // False
Console.WriteLine (x.Equals (y));  // True
```

Because `x` and `y` have been cast to the `object` type, the compiler statically binds to `object`’s `==` operator, which uses *reference-type* semantics to compare two instances. (And because `x` and `y` are boxed, they are represented in separate memory locations, and so are unequal.) The virtual `Equals` method, however, defers to the `Int32` type’s `Equals` method, which uses *value-type* semantics in comparing two values.

The static `object.Equals` method simply calls the virtual `Equals` method on the first argument—after checking that the arguments are not null:
object x = null, y = 3;
bool error = x.Equals (y);        // Runtime error!
bool ok = object.Equals (x, y);   // OK (false)

ReferenceEquals forces a reference-type equality comparison (this is occasionally useful on reference types where the == operator has been overloaded to do otherwise).


To customize a type’s equality semantics, you must at a minimum override Equals and GetHashCode. You would also usually overload the == and != operators. For an example of how to do both, see “Operator Overloading” on page 136.

The ToString Method

The ToString method returns the default textual representation of a type instance. The ToString method is overridden by all built-in types:

```csharp
string s1 = 1.ToString();      // s1 is "1"
string s2 = true.ToString();   // s2 is "True"
```

You can override the ToString method on custom types as follows:

```csharp
public override string ToString() { return "Foo"; }
```

Structs

A struct is similar to a class, with the following key differences:

- A struct is a value type, whereas a class is a reference type.
- A struct does not support inheritance (other than implicitly deriving from object, or more precisely, System.ValueType).

A struct can have all the members a class can, except for a parameterless constructor, a finalizer, and virtual members.
A struct is used instead of a class when value-type semantics are desirable. Good examples are numeric types, where it is more natural for assignment to copy a value rather than a reference. Because a struct is a value type, each instance does not require instantiation of an object on the heap; this can incur a useful saving when creating many instances of a type. For instance, creating an array of a value type requires only a single heap allocation.

**Struct Construction Semantics**

The construction semantics of a struct are as follows:

- A parameterless constructor that you can’t override implicitly exists. This performs a bitwise-zeroing of its fields.
- When you define a struct constructor (with parameters), you must explicitly assign every field.
- You can’t have field initializers in a struct.

**Access Modifiers**

To promote encapsulation, a type or type member may limit its accessibility to other types and other assemblies by adding one of five access modifiers to the declaration:

- **public**
  Fully accessible. This is the implicit accessibility for members of an enum or interface.

- **internal**
  Accessible only within the containing assembly or friend assemblies. This is the default accessibility for non-nested types.

- **private**
  Accessible only within the containing type. This is the default accessibility for members of a class or struct.

- **protected**
  Accessible only within the containing type or subclasses.
protected internal

The union of protected and internal accessibility (this is more permissive than protected or internal alone, in that it makes a member more accessible in two ways).

In the following example, Class2 is accessible from outside its assembly; Class1 is not:

```csharp
class Class1 {}         // Class1 is internal (default)
public class Class2 {}
```

ClassB exposes field x to other types in the same assembly; ClassA does not:

```csharp
class ClassA { int x;       }  // x is private
class ClassB { internal int x; }
```

When overriding a base class function, accessibility must be identical on the overridden function. The compiler prevents any inconsistent use of access modifiers—for example, a subclass itself can be less accessible than a base class, but not more.

**Friend Assemblies**

In advanced scenarios, you can expose internal members to other friend assemblies by adding the `System.Runtime.CompilerServices.InternalsVisibleTo` assembly attribute, specifying the name of the friend assembly as follows:

```csharp
[assembly: InternalsVisibleTo ("Friend")]
```

If the friend assembly is signed with a strong name, you must specify its full 160-byte public key. You can extract this key via a LINQ query—an interactive example is given in LINQPad’s free sample library for *C# 5.0 in a Nutshell*.

**Accessibility Capping**

A type caps the accessibility of its declared members. The most common example of capping is when you have an internal type with public members. For example:

```csharp
class C { public void Foo() {} }
```
C’s (default) *internal* accessibility caps Foo’s accessibility, effectively making Foo *internal*. A common reason Foo would be marked *public* is to make for easier refactoring, should C later be changed to *public*.

## Interfaces

An interface is similar to a class, but it provides a specification rather than an implementation for its members. An interface is special in the following ways:

- Interface members are *all implicitly abstract*. In contrast, a class can provide both abstract members and concrete members with implementations.

- A class (or struct) can implement *multiple* interfaces. In contrast, a class can inherit from only a *single* class, and a struct cannot inherit at all (aside from deriving from `System.ValueType`).

An interface declaration is like a class declaration, but it provides no implementation for its members, since all its members are implicitly abstract. These members will be implemented by the classes and structs that implement the interface. An interface can contain only methods, properties, events, and indexers, which noncoincidentally are precisely the members of a class that can be abstract.

Here is a slightly simplified version of the `IEnumerator` interface, defined in `System.Collections`:

```csharp
public interface IEnumerator
{
    bool MoveNext();
    object Current { get; }
}
```

Interface members are always implicitly public and cannot declare an access modifier. Implementing an interface means providing a *public* implementation for all its members:

```csharp
internal class Countdown : IEnumerator
{
```

86 | C# 5.0 Pocket Reference
You can implicitly cast an object to any interface that it implements:

```csharp
IEnumerator e = new Countdown();
while (e.MoveNext())
    Console.Write (e.Current);      // 109876543210
```

### Extending an Interface

Interfaces may derive from other interfaces. For instance:

```csharp
public interface IUndoable
    { void Undo(); }
public interface IRedoable : IUndoable { void Redo(); }
```

IRedoable “inherits” all the members of IUndoable.

### Explicit Interface Implementation

Implementing multiple interfaces can sometimes result in a collision between member signatures. You can resolve such collisions by *explicitly implementing* an interface member. For example:

```csharp
interface I1 { void Foo(); }
interface I2 { int Foo(); }

public class Widget : I1, I2
{
    public void Foo()   // Implicit implementation
    {
        Console.Write ("Widget's implementation of I1.Foo");
    }

    int I2.Foo()   // Explicit implementation of I2.Foo
    {
        Console.Write ("Widget's implementation of I2.Foo");
        return 42;
    }
}
```
Because both I1 and I2 have conflicting Foo signatures, Widget explicitly implements I2’s Foo method. This lets the two methods coexist in one class. The only way to call an explicitly implemented member is to cast to its interface:

```csharp
Widget w = new Widget();
w.Foo();           // Widget's implementation of I1.Foo
((I1)w).Foo();     // Widget's implementation of I1.Foo
((I2)w).Foo();     // Widget's implementation of I2.Foo
```

Another reason to explicitly implement interface members is to hide members that are highly specialized and distracting to a type’s normal use case. For example, a type that implements ISerializable would typically want to avoid flaunting its ISerializable members unless explicitly cast to that interface.

### Implementing Interface Members Virtually

An implicitly implemented interface member is, by default, sealed. It must be marked `virtual` or `abstract` in the base class in order to be overridden: calling the interface member through either the base class or the interface then calls the subclass’s implementation.

An explicitly implemented interface member cannot be marked `virtual`, nor can it be overridden in the usual manner. It can, however, be **reimplemented**.

### Reimplementing an Interface in a Subclass

A subclass can **reimplement** any interface member already implemented by a base class. Reimplementation hijacks a member implementation (when called through the interface) and works whether or not the member is `virtual` in the base class.

In the following example, TextBox implements IUndo.Undo explicitly, and so it cannot be marked as `virtual`. In order to “override” it, RichTextBox must reimplement IUndo’s Undo method:
public interface IUndoable { void Undo(); }

public class TextBox : IUndoable
{
    void IUndoable.Undo()
    { Console.WriteLine("TextBox.Undo"); }
}

public class RichTextBox : TextBox, IUndoable
{
    public new void Undo()
    { Console.WriteLine("RichTextBox.Undo"); }
}

Calling the reimplemented member through the interface calls the subclass’s implementation:

RichTextBox r = new RichTextBox();
r.Undo();                 // RichTextBox.Undo
((IUndoable)r).Undo();    // RichTextBox.Undo

In this case, Undo is implemented explicitly. Implicitly implemented members can also be reimplemented, but the effect is nonpervasive in that calling the member through the base class invokes the base implementation.

Enums

An enum is a special value type that lets you specify a group of named numeric constants. For example:

public enum BorderSide { Left, Right, Top, Bottom }

We can use this enum type as follows:

BorderSide topSide = BorderSide.Top;
bool isTop = (topSide == BorderSide.Top);   // true

Each enum member has an underlying integral value. By default, the underlying values are of type int, and the enum members are assigned the constants 0, 1, 2... (in their declaration order). You may specify an alternative integral type, as follows:

public enum BorderSide : byte { Left, Right, Top, Bottom }
You may also specify an explicit integral value for each member:

```csharp
public enum BorderSide : byte
{ Left=1, Right=2, Top=10, Bottom=11 }
```

The compiler also lets you explicitly assign some of the enum members. The unassigned enum members keep incrementing from the last explicit value. The preceding example is equivalent to:

```csharp
public enum BorderSide : byte
{ Left=1, Right, Top=10, Bottom }
```

### Enum Conversions

You can convert an enum instance to and from its underlying integral value with an explicit cast:

```csharp
int i = (int) BorderSide.Left;
BorderSide side = (BorderSide) i;
bool leftOrRight = (int) side <= 2;
```

You can also explicitly cast one enum type to another; the translation then uses the members’ underlying integral values. The numeric literal 0 is treated specially, in that it does not require an explicit cast:

```csharp
BorderSide b = 0;    // No cast required
if (b == 0) ...
```

In this particular example, `BorderSide` has no member with an integral value of 0. This does not generate an error: a limitation of enums is that the compiler and CLR do not prevent the assignment of integrals whose values fall outside the range of members:

```csharp
BorderSide b = (BorderSide) 12345;
Console.WriteLine (b);              // 12345
```
**Flags Enums**

You can combine enum members. To prevent ambiguities, members of a combinable enum require explicitly assigned values, typically in powers of two. For example:

```csharp
[Flags]
public enum BorderSides
{ None=0, Left=1, Right=2, Top=4, Bottom=8 }
```

By convention, a combinable enum type is given a plural rather than singular name. To work with combined enum values, you use bitwise operators, such as | and &. These operate on the underlying integral values:

```csharp
BorderSides leftRight =
    BorderSides.Left | BorderSides.Right;

if ((leftRight & BorderSides.Left) != 0)
    Console.WriteLine("Includes Left"); // Includes Left

string formatted = leftRight.ToString(); // "Left, Right"

BorderSides s = BorderSides.Left;
s |= BorderSides.Right;
Console.WriteLine(s == leftRight); // True
```

The **Flags** attribute should be applied to combinable enum types; if you fail to do this, calling `ToString` on an enum instance emits a number rather than a series of names.

For convenience, you can include combination members within an enum declaration itself:

```csharp
[Flags] public enum BorderSides
{
    None=0,
    Left=1, Right=2, Top=4, Bottom=8,
    LeftRight = Left | Right,
    TopBottom = Top | Bottom,
    All       = LeftRight | TopBottom
}
```
Enum Operators

The operators that work with enums are:

```
=   ==   !=   <   >   <=   >=   +   -   ^  &  |  ~
+=  -=   ++   -   sizeof
```

The bitwise, arithmetic, and comparison operators return the result of processing the underlying integral values. Addition is permitted between an enum and an integral type, but not between two enums.

Nested Types

A nested type is declared within the scope of another type. For example:

```csharp
public class TopLevel
{
    public class Nested { }               // Nested class
    public enum Color { Red, Blue, Tan }  // Nested enum
}
```

A nested type has the following features:

- It can access the enclosing type’s private members and everything else the enclosing type can access.
- It can be declared with the full range of access modifiers, rather than just public and internal.
- The default accessibility for a nested type is private rather than internal.
- Accessing a nested type from outside the enclosing type requires qualification with the enclosing type’s name (like when accessing static members).

For example, to access Color.Red from outside our TopLevel class, we’d have to do this:

```
TopLevel.Color color = TopLevel.Color.Red;
```

All types can be nested; however, only classes and structs can nest.
Generics

C# has two separate mechanisms for writing code that is reusable across different types: inheritance and generics. Whereas inheritance expresses reusability with a base type, generics express reusability with a “template” that contains “placeholder” types. Generics, when compared to inheritance, can increase type safety and reduce casting and boxing.

Generic Types

A generic type declares type parameters—placeholder types to be filled in by the consumer of the generic type, which supplies the type arguments. Here is a generic type, Stack<T>, designed to stack instances of type T. Stack<T> declares a single type parameter T:

```csharp
public class Stack<T>
{
    int position;
    T[] data = new T[100];
    public void Push (T obj) { data[position++] = obj;  }
    public T Pop()           { return data[--position]; }
}
```

We can use Stack<T> as follows:

```csharp
Stack<int> stack = new Stack<int>();
stack.Push(5);
stack.Push(10);
int x = stack.Pop(); // x is 10
int y = stack.Pop(); // y is 5
```

NOTE

Notice that no downcasts are required in the last two lines, avoiding the possibility of a runtime error and eliminating the overhead of boxing/unboxing. This makes our generic stack superior to a nongeneric stack that uses object in place of T (see “The object Type” on page 79 for an example).
Stack<int> fills in the type parameter T with the type argument int, implicitly creating a type on the fly (the synthesis occurs at runtime). Stack<int> effectively has the following definition (substitutions appear in bold, with the class name hashed out to avoid confusion):

```csharp
public class ###
{
    int position;
    int[] data;
    public void Push (int obj) { data[position++] = obj;  }
    public int Pop()           { return data[--position]; }
}
```

Technically, we say that Stack<T> is an open type, whereas Stack<int> is a closed type. At runtime, all generic type instances are closed—with the placeholder types filled in.

### Generic Methods

A generic method declares type parameters within the signature of a method. With generic methods, many fundamental algorithms can be implemented in a general-purpose way only. Here is a generic method that swaps the contents of two variables of any type T:

```csharp
static void Swap<T> (ref T a, ref T b)
{
    T temp = a; a = b; b = temp;
}
```

Swap<T> can be used as follows:

```csharp
int x = 5, y = 10;
Swap (ref x, ref y);
```

Generally, there is no need to supply type arguments to a generic method, because the compiler can implicitly infer the type. If there is ambiguity, generic methods can be called with the type arguments as follows:

```csharp
Swap<int> (ref x, ref y);
```

Within a generic type, a method is not classed as generic unless it introduces type parameters (with the angle bracket syntax).
The `Pop` method in our generic stack merely consumes the type’s existing type parameter, `T`, and is not classed as a generic method.

Methods and types are the only constructs that can introduce type parameters. Properties, indexers, events, fields, constructors, operators, and so on cannot declare type parameters, although they can partake in any type parameters already declared by their enclosing type. In our generic stack example, for instance, we could write an indexer that returns a generic item:

```csharp
public T this [int index] { get { return data[index]; } }
```

Similarly, constructors can partake in existing type parameters, but cannot introduce them.

**Declaring Type Parameters**

Type parameters can be introduced in the declaration of classes, structs, interfaces, delegates (see the section “Delegates” on page 101), and methods. A generic type or method can have multiple parameters:

```csharp
class Dictionary<TKey, TValue> {...}
```

To instantiate:

```csharp
var myDic = new Dictionary<int,string>();
```

Generic type names and method names can be overloaded as long as the number of type parameters differs. For example, the following two type names do not conflict. For example, the following two type names do not conflict:

```csharp
class A<T> {}
class A<T1,T2> {}
```
NOTE

By convention, generic types and methods with a *single* type parameter name their parameter \( T \), as long as the intent of the parameter is clear. With *multiple* type parameters, each parameter has a more descriptive name (prefixed by \( T \)).

typeof and Unbound Generic Types

Open generic types do not exist at runtime: open generic types are closed as part of compilation. However, it is possible for an *unbound* generic type to exist at runtime—purely as a Type object. The only way to specify an unbound generic type in C# is with the `typeof` operator:

```csharp
class A<T> {}
class A<T1,T2> {}...

Type a1 = typeof (A<>);   // Unbound type
Type a2 = typeof (A<,>);  // Indicates 2 type args
Console.Write (a2.GetGenericArguments().Count());  // 2
```

You can also use the `typeof` operator to specify a closed type:

```csharp
Type a3 = typeof (A<int,int>);
```

or an open type (which is closed at runtime):

```csharp
class B<T> { void X() { Type t = typeof (T); } } ...
```

The default Generic Value

The `default` keyword can be used to get the default value given for a generic type parameter. The default value for a reference type is `null`, and the default value for a value type is the result of bitwise-zeroing the type’s fields:

```csharp
static void Zap<T> (T[] array)
{
    for (int i = 0; i < array.Length; i++)
        array[i] = default(T);
}
```
Generic Constraints

By default, a type parameter can be substituted with any type whatsoever. *Constraints* can be applied to a type parameter to require more specific type arguments. There are six kinds of constraint:

```csharp
    where T : base-class       // Base-class constraint
    where T : interface       // Interface constraint
    where T : class           // Reference-type constraint
    where T : struct          // Value-type constraint
    where T : new()           // Parameterless constructor
    where U : T               // Naked type constraint
```

In the following example, `GenericClass<T,U>` requires `T` to derive from (or be identical to) `SomeClass` and implement `Interface1`, and requires `U` to provide a parameterless constructor:

```csharp
    class     SomeClass {}  
    interface Interface1 {} 

    class GenericClass<T,U> where T : SomeClass, Interface1 
                                where U : new() 
    { ... } 
```

Constraints can be applied wherever type parameters are defined, whether in methods or in type definitions.

A *base-class constraint* specifies that the type parameter must subclass (or match) a particular class; an *interface constraint* specifies that the type parameter must implement that interface. These constraints allow instances of the type parameter to be implicitly converted to that class or interface.

The *class constraint* and *struct constraint* specify that `T` must be a reference type or a (non-nullable) value type, respectively. The *parameterless constructor constraint* requires `T` to have a public parameterless constructor and allows you to call `new()` on `T`:
static void Initialize<T> (T[] array) where T : new()
{
    for (int i = 0; i < array.Length; i++)
        array[i] = new T();
}

The *naked type constraint* requires one type parameter to derive from (or match) another type parameter.

**Subclassing Generic Types**

A generic class can be subclassed just like a nongeneric class. The subclass can leave the base class’s type parameters open, as in the following example:

```csharp
class Stack<T>                   {...}
class SpecialStack<T> : Stack<T> {...}
```

Or the subclass can close the generic type parameters with a concrete type:

```csharp
class IntStack : Stack<int>   {...}
```

A subtype can also introduce fresh type arguments:

```csharp
class List<T>                     {...}
class KeyedList<T, TKey> : List<T> {...}
```

**Self-Referencing Generic Declarations**

A type can name *itself* as the concrete type when closing a type argument:

```csharp
public interface IEquatable<T> { bool Equals (T obj); }

public class Balloon : IEquatable<Balloon>
{
    public bool Equals (Balloon b) { ... }
}
```

The following are also legal:

```csharp
class Foo<T> where T : IComparable<T> { ... }
class Bar<T> where T : Bar<T> { ... }
```
**Static Data**

Static data is unique for each closed type:

```csharp
class Bob<T> { public static int Count; }
...
Console.WriteLine (++Bob<int>.Count);    // 1
Console.WriteLine (++Bob<int>.Count);    // 2
Console.WriteLine (++Bob<string>.Count); // 1
Console.WriteLine (++Bob<object>.Count); // 1
```

**Covariance**

Assuming $A$ is convertible to $B$, $X$ is covariant if $X<A>$ is convertible to $X<B>$.

---

**NOTE**

Covariance and contravariance are advanced concepts. The motivation behind their introduction into C# was to allow generic interfaces and generics (in particular, those defined in the Framework, such as IEnumerable<T>) to work more as you’d expect. You can benefit from this without understanding the details behind covariance and contravariance.

(With C#’s notion of variance, “convertible” means convertible via an implicit reference conversion—such as $A$ subclassing $B$, or $A$ implementing $B$. Numeric conversions, boxing conversions, and custom conversions are not included.)

For instance, type IFoo<T> is covariant for T if the following is legal:

```csharp
IFoo<string> s = ...;
IFoo<object> b = s;
```

As of C# 4.0, generic interfaces permit covariance for type parameters marked with the out modifier (as do generic delegates). To illustrate, suppose that the Stack<T> class that we wrote at the start of this section implements the following interface:
public interface IPoppable<out T> { T Pop(); }

The `out` modifier on `T` indicates that `T` is used only in output positions (e.g., return types for methods). The `out` modifier flags the interface as covariant and allows us to do this:

```csharp
// Assuming that Bear subclasses Animal:
var bears = new Stack<Bear>();
bears.Push (new Bear());

// Because bears implements IPoppable<Bear>,
// we can convert it to IPoppable<Animal>:
IPoppable<Animal> animals = bears; // Legal
Animal a = animals.Pop();
```

The cast from `bears` to `animals` is permitted by the compiler—by virtue of the interface being covariant.

---

**NOTE**

The `IEnumerable<T>` and `IEnumerable<T>` interfaces (see “Enumeration and Iterators” on page 126) are marked as covariant from Framework 4.0. This allows you to cast `IEnumerable<string>` to `IEnumerable<object>`, for instance.

The compiler will generate an error if you use a covariant type parameter in an input position (e.g., a parameter to a method or a writable property). The purpose of this limitation is to guarantee compile-time type safety. For instance, it prevents us from adding a `Push(T)` method to that interface which consumers could abuse with the seemingly benign operation of pushing a Camel onto an `IPoppable<Animal>` (remember that the underlying type in our example is a stack of bears). In order to define a `Push(T)` method, `T` must in fact be contravariant.
NOTE

C# supports covariance (and contravariance) only for elements with reference conversions—not boxing conversions. So, if you wrote a method that accepted a parameter of type IPoppable<object>, you could call it with IPoppable<string>, but not IPoppable<int>.

Contravariance

We previously saw that, assuming that A allows an implicit reference conversion to B, a type X is covariant if X<A> allows a reference conversion to X<B>. A type is contravariant when you can convert in the reverse direction—from X<B> to X<A>. This is supported on interfaces and delegates when the type parameter only appears in input positions, designated with the in modifier. Extending our previous example, if the Stack<T> class implements the following interface:

```csharp
public interface IPushable<in T> { void Push (T obj); }
```

we can legally do this:

```csharp
IPushable<Animal> animals = new Stack<Animal>();
IPushable<Bear> bears = animals;    // Legal
bears.Push (new Bear());
```

Mirroring covariance, the compiler will report an error if you try to use a contravariant type parameter in an output position (e.g., as a return value, or in a readable property).

Delegates

A delegate wires up a method caller to its target method at runtime. There are two aspects to a delegate: type and instance. A delegate type defines a protocol to which the caller and target will conform, comprising a list of parameter types and a return type. A delegate instance is an object that refers to one (or more) target methods conforming to that protocol.
A delegate instance literally acts as a delegate for the caller: the caller invokes the delegate, and then the delegate calls the target method. This indirection decouples the caller from the target method.

A delegate type declaration is preceded by the keyword `delegate`, but otherwise it resembles an (abstract) method declaration. For example:

```csharp
delegate int Transformer(int x);
```

To create a delegate instance, you can assign a method to a delegate variable:

```csharp
class Test
{
    static void Main()
    {
        Transformer t = Square;  // Create delegate instance
        int result = t(3);       // Invoke delegate
        Console.WriteLine(result); // 9
    }
    static int Square(int x) { return x * x; }
}
```

Invoking a delegate is just like invoking a method (since the delegate’s purpose is merely to provide a level of indirection):

```csharp
t(3);
```

The statement `Transformer t = Square` is shorthand for:

```csharp
Transformer t = new Transformer(Square);
```

And `t(3)` is shorthand for:

```csharp
t.Invoke(3);
```

A delegate is similar to a *callback*, a general term that captures constructs such as C function pointers.

**Writing Plug-in Methods with Delegates**

A delegate variable is assigned a method at runtime. This is useful for writing plug-in methods. In this example, we have a utility method named `Transform` that applies a transform to
each element in an integer array. The Transform method has a delegate parameter, for specifying a plug-in transform.

```csharp
public delegate int Transformer (int x);

class Test
{
    static void Main()
    {
        int[] values = { 1, 2, 3 };
        Transform (values, Square);
        foreach (int i in values)
            Console.Write (i + " ");  // 1 4 9
    }

    static void Transform (int[] values, Transformer t)
    {
        for (int i = 0; i < values.Length; i++)
            values[i] = t (values[i]);
    }

    static int Square (int x) { return x * x; }
}
```

**Multicast Delegates**

All delegate instances have multicast capability. This means that a delegate instance can reference not just a single target method, but also a list of target methods. The + and += operators combine delegate instances. For example:

```csharp
SomeDelegate d = SomeMethod1;
d += SomeMethod2;
```

The last line is functionally the same as:

```csharp
d = d + SomeMethod2;
```

Invoking d will now call both SomeMethod1 and SomeMethod2. Delegates are invoked in the order they are added.

The - and -= operators remove the right delegate operand from the left delegate operand. For example:

```csharp
d -= SomeMethod1;
```

Invoking d will now cause only SomeMethod2 to be invoked.
Calling + or += on a delegate variable with a null value is legal, as is calling -= on a delegate variable with a single target (which will result in the delegate instance being null).

**NOTE**

Delegates are **immutable**, so when you call += or -=, you’re in fact creating a new delegate instance and assigning it to the existing variable.

If a multicast delegate has a nonvoid return type, the caller receives the return value from the last method to be invoked. The preceding methods are still called, but their return values are discarded. In most scenarios in which multicast delegates are used, they have **void** return types, so this subtlety does not arise.

All delegate types implicitly derive from `System.MulticastDelegate`, which inherits from `System.Delegate`. C# compiles +, -, +=, and -= operations made on a delegate to the static `Combine` and `Remove` methods of the `System.Delegate` class.

**Instance Versus Static Method Targets**

When an *instance* method is assigned to a delegate object, the latter must maintain a reference not only to the method, but also to the *instance* to which the method belongs. The `System.Delegate` class’s `Target` property represents this instance (and will be null for a delegate referencing a static method).

**Generic Delegate Types**

A delegate type may contain generic type parameters. For example:

```csharp
public delegate T Transformer<T> (T arg);
```

Here’s how we could use this delegate type:
The Func and Action Delegates

With generic delegates, it becomes possible to write a small set of delegate types that are so general they can work for methods of any return type and any (reasonable) number of arguments. These delegates are the Func and Action delegates, defined in the System namespace (the in and out annotations indicate variance, which we will cover shortly):

- delegate TResult Func<out TResult>();
- delegate TResult Func<in T, out TResult>(T arg);
- delegate TResult Func<in T1, in T2, out TResult>(T1 arg1, T2 arg2);

... and so on, up to T16

- delegate void Action();
- delegate void Action<in T>(T arg);
- delegate void Action<in T1, in T2>(T1 arg1, T2 arg2);

... and so on, up to T16

These delegates are extremely general. The Transformer delegate in our previous example can be replaced with a Func delegate that takes a single argument of type T and returns a same-typed value:

```csharp
public static void Transform<T>(
    T[] values, Func<T, T> transformer)
{
    for (int i = 0; i < values.Length; i++)
        values[i] = transformer(values[i]);
}
```

The only practical scenarios not covered by these delegates are ref/out and pointer parameters.
Delegate Compatibility

Delegate types are all incompatible with one another, even if their signatures are the same:

```csharp
delegate void D1();
delegate void D2(); ...
D1 d1 = Method1;
D2 d2 = d1;            // Compile-time error
```

The following, however, is permitted:

```csharp
D2 d2 = new D2 (d1);
```

Delegate instances are considered equal if they have the same type and method target(s). For multicast delegates, the order of the method targets is significant.

Return type variance

When you call a method, you may get back a type that is more specific than what you asked for. This is ordinary polymorphic behavior. In keeping with this, a delegate target method may return a more specific type than described by the delegate. This is covariance, and has been supported since C# 2.0:

```csharp
delegate object ObjectRetriever();
...
static void Main()
{
    ObjectRetriever o = new ObjectRetriever (GetString);
    object result = o();
    Console.WriteLine (result);       // hello
}
static string GetString() { return "hello"; }
```

The `ObjectRetriever` expects to get back an `object`, but an `object` subclass will also do because delegate return types are covariant.

Parameter variance

When you call a method, you can supply arguments that have more specific types than the parameters of that method. This is ordinary polymorphic behavior. In keeping with this, a del-
egate target method may have less specific parameter types than described by the delegate. This is called contravariance:

delegate void StringAction (string s);
...
static void Main()
{
    StringAction sa = new StringAction (ActOnObject);
    sa ("hello");
}
static void ActOnObject (object o)
{
    Console.WriteLine (o);   // hello
}

NOTE

The standard event pattern is designed to help you leverage delegate parameter contravariance through its use of the common EventArgs base class. For example, you can have a single method invoked by two different delegates, one passing a MouseEventArgs and the other passing a KeyEventArgs.

Type parameter variance for generic delegates

We saw in “Generics” on page 93 how type parameters can be covariant and contravariant for generic interfaces. The same capability also exists for generic delegates from C# 4.0. If you’re defining a generic delegate type, it’s a good practice to:

• Mark a type parameter used only on the return value as covariant (out).
• Mark any type parameters used only on parameters as contravariant (in).

Doing so allows conversions to work naturally by respecting inheritance relationships between types. The following delegate (defined in the System namespace) is covariant for TResult:

delegate TResult Func<out TResult>();

allowing:
Func<string> x = ...;
Func<object> y = x;

The following delegate (defined in the System namespace) is contravariant for T:

delegate void Action<in T> (T arg);

allowing:

Action<object> x = ...;
Action<string> y = x;

## Events

When using delegates, two emergent roles commonly appear: broadcaster and subscriber. The broadcaster is a type that contains a delegate field. The broadcaster decides when to broadcast, by invoking the delegate. The subscribers are the method target recipients. A subscriber decides when to start and stop listening, by calling += and -= on the broadcaster’s delegate. A subscriber does not know about, or interfere with, other subscribers.

Events are a language feature that formalizes this pattern. An event is a construct that exposes just the subset of delegate features required for the broadcaster/subscriber model. The main purpose of events is to prevent subscribers from interfering with one another.

The easiest way to declare an event is to put the event keyword in front of a delegate member:

```csharp
public class Broadcaster
{
    public event ProgressReporter Progress;
}
```

Code within the Broadcaster type has full access to Progress and can treat it as a delegate. Code outside of Broadcaster can only perform += and -= operations on the Progress event.

In the following example, the Stock class fires its Price Changed event every time the Price of the Stock changes:
public delegate void PriceChangedHandler (decimal oldPrice, decimal newPrice);

public class Stock
{
    string symbol; decimal price;

    public Stock (string symbol) { this.symbol = symbol; }

    public event PriceChangedHandler PriceChanged;

    public decimal Price
    {
        get { return price; }
        set
        {
            if (price == value) return;
            // Fire event if invocation list isn't empty:
            if (PriceChanged != null)
                PriceChanged (price, value);
            price = value;
        }
    }
}

If we remove the event keyword from our example so that PriceChanged becomes an ordinary delegate field, our example would give the same results. However, Stock would be less robust, in that subscribers could do the following things to interfere with one another:

- Replace other subscribers by reassigning PriceChanged (instead of using the += operator).
- Clear all subscribers (by setting PriceChanged to null).
- Broadcast to other subscribers by invoking the delegate.

Events can be virtual, overridden, abstract, or sealed. They can also be static.

**Standard Event Pattern**

The .NET Framework defines a standard pattern for writing events. Its purpose is to provide consistency across both
Framework and user code. Here’s the preceding example refactored with this pattern:

```csharp
public class PriceChangedEventArgs : EventArgs
{
    public readonly decimal LastPrice, NewPrice;

    public PriceChangedEventArgs (decimal lastPrice, decimal newPrice)
    {
        LastPrice = lastPrice; NewPrice = newPrice;
    }
}

public class Stock
{
    string symbol; decimal price;

    public Stock (string symbol) { this.symbol = symbol; }

    public event EventHandler<PriceChangedEventArgs> PriceChanged;

    protected virtual void OnPriceChanged (PriceChangedEventArgs e)
    {
        if (PriceChanged != null) PriceChanged (this, e);
    }

    public decimal Price
    {
        get { return price; } 
        set
        {
            if (price == value) return;
            OnPriceChanged (new PriceChangedEventArgs (price, value));
            price = value;
        }
    }
}
```

At the core of the standard event pattern is `System.EventArgs`: a predefined Framework class with no members (other than the static `Empty` property). `EventArgs` is a base class for conveying information for an event. In this example, we subclass
EventArgs to convey the old and new prices when a Price Changed event is fired.

The generic System.EventHandler delegate is also part of the .NET Framework and is defined as follows:

```csharp
public delegate void EventHandler<TEventArgs>
    (object source, TEventArgs e)
    where TEventArgs : EventArgs;
```

**NOTE**

Before C# 2.0 (when generics were added to the language) the solution was to instead write a custom event handling delegate for each EventArgs type as follows:

```csharp
delegate void PriceChangedHandler
    (object sender,
     PriceChangedEventArgs e);
```

For historical reasons, most events within the Framework use delegates defined in this way.

A protected virtual method, named `On-event-name`, centralizes firing of the event. This allows subclasses to fire the event (which is usually desirable) and also allows subclasses to insert code before and after the event is fired.

Here’s how we could use our Stock class:

```csharp
static void Main()
{
    Stock stock = new Stock("THPW");
    stock.Price = 27.10M;

    stock.PriceChanged += stock_PriceChanged;
    stock.Price = 31.59M;
}

static void stock_PriceChanged
    (object sender, PriceChangedEventArgs e)
{
    if ((e.NewPrice - e.LastPrice) / e.LastPrice > 0.1M)
        Console.WriteLine("Alert, 10% price increase!");
}
```
For events that don’t carry additional information, the Framework also provides a nongeneric EventHandler delegate. We can demonstrate this by rewriting our Stock class such that the PriceChanged event fires after the price changes. This means that no additional information need be transmitted with the event:

```csharp
public class Stock
{
    string symbol; decimal price;

    public Stock (string symbol) {this.symbol = symbol;}

    public event EventHandler PriceChanged;

    protected virtual void OnPriceChanged (EventArgs e)
    {
        if (PriceChanged != null) PriceChanged (this, e);
    }

    public decimal Price
    {
        get { return price; }
        set
        {
            if (price == value) return;
            price = value;
            OnPriceChanged (EventArgs.Empty);
        }
    }
}
```

Note that we also used the EventArgs.Empty property—this saves instantiating an instance of EventArgs.

**Event Accessors**

An event’s *accessors* are the implementations of its += and -= functions. By default, accessors are implemented implicitly by the compiler. Consider this event declaration:

```csharp
public event EventHandler PriceChanged;
```

The compiler converts this to the following:
• A private delegate field
• A public pair of event accessor functions, whose implementations forward the += and -= operations to the private delegate field

You can take over this process by defining explicit event accessors. Here’s a manual implementation of the PriceChanged event from our previous example:

```c#
EventHandler _priceChanged; // Private delegate
public event EventHandler PriceChanged
{
    add { _priceChanged += value; }
    remove { _priceChanged -= value; }
}
```

This example is functionally identical to C#'s default accessor implementation (except that C# also ensures thread safety around updating the delegate). By defining event accessors ourselves, we instruct C# not to generate default field and accessor logic.

With explicit event accessors, you can apply more complex strategies to the storage and access of the underlying delegate. This is useful when the event accessors are merely relays for another class that is broadcasting the event, or when explicitly implementing an interface that declares an event:

```c#
public interface IFoo { event EventHandler Ev; }
class Foo : IFoo
{
    EventHandler ev;
    event EventHandler IFoo.Ev
    {
        add { ev += value; } remove { ev -= value; }
    }
}
```

### Lambda Expressions

A lambda expression is an unnamed method written in place of a delegate instance. The compiler immediately converts the lambda expression to either:
• A delegate instance.

• An expression tree, of type Expression<TDelegate>, representing the code inside the lambda expression in a traversable object model. This allows the lambda expression to be interpreted later at runtime (we describe the process in Chapter 8 of C# 5.0 in a Nutshell).

Given the following delegate type:

delegate int Transformer (int i);

we could assign and invoke the lambda expression \( x \Rightarrow x \times x \) as follows:

```csharp
Transformer sqr = x => x * x;
Console.WriteLine (sqr(3));    // 9
```

NOTE

Internally, the compiler resolves lambda expressions of this type by writing a private method, and moving the expression’s code into that method.

A lambda expression has the following form:

\((\text{parameters}) \Rightarrow \text{expression-or-statement-block}\)

For convenience, you can omit the parentheses if and only if there is exactly one parameter of an inferable type.

In our example, there is a single parameter, \( x \), and the expression is \( x \times x \):

\( x \Rightarrow x \times x \)

Each parameter of the lambda expression corresponds to a delegate parameter, and the type of the expression (which may be void) corresponds to the return type of the delegate.

In our example, \( x \) corresponds to parameter \( i \), and the expression \( x \times x \) corresponds to the return type int, therefore being compatible with the Transformer delegate.
A lambda expression’s code can be a statement block instead of an expression. We can rewrite our example as follows:

```csharp
x => { return x * x; };
```

Lambda expressions are used most commonly with the Func and Action delegates, so you will most often see our earlier expression written as follows:

```csharp
Func<int, int> sqr = x => x * x;
```

The compiler can usually infer the type of lambda parameters contextually. When this is not the case, you can specify parameter types compiler:

```csharp
Func<int, int> sqr = (int x) => x * x;
```

Here’s an example of an expression that accepts two parameters:

```csharp
Func<string, string, int> totalLength = (s1, s2) => s1.Length + s2.Length;

int total = totalLength("hello", "world"); // total=10;
```

Assuming Clicked is an event of type EventHandler, the following attaches an event handler via a lambda expression:

```csharp
obj.Clicked += (sender, args) => Console.Write("Click");
```

### Capturing Outer Variables

A lambda expression can reference the local variables and parameters of the method in which it’s defined (outer variables). For example:

```csharp
static void Main()
{
    int factor = 2;
    Func<int, int> multiplier = n => n * factor;
    Console.WriteLine(multiplier(3)); // 6
}
```

Outer variables referenced by a lambda expression are called captured variables. A lambda expression that captures variables is called a closure. Captured variables are evaluated when
the delegate is actually *invoked*, not when the variables were *captured*:

```csharp
int factor = 2;
Func<int, int> multiplier = n => n * factor;
factor = 10;
Console.WriteLine(multiplier(3));           // 30
```

Lambda expressions can themselves update captured variables:

```csharp
int seed = 0;
Func<int> natural = () => seed++;
Console.WriteLine(natural());           // 0
Console.WriteLine(natural());           // 1
Console.WriteLine(seed);                // 2
```

Captured variables have their lifetimes extended to that of the delegate. In the following example, the local variable `seed` would ordinarily disappear from scope when `Natural` finished executing. But because `seed` has been *captured*, its lifetime is extended to that of the capturing delegate, `natural`:

```csharp
static Func<int> Natural()
{
  int seed = 0;
  return () => seed++;      // Returns a closure
}
static void Main()
{
  Func<int> natural = Natural();
  Console.WriteLine(natural());  // 0
  Console.WriteLine(natural());  // 1
}
```

**Capturing iteration variables**

When you capture an iteration variable in a `for` loop, C# treats the iteration variable as though it was declared *outside* the loop. This means that the *same* variable is captured in each iteration. The following program writes `333` instead of writing `012`:

```csharp
Action[] actions = new Action[3];

for (int i = 0; i < 3; i++)
  actions[i] = () => Console.Write(i);
```
foreach (Action a in actions) a();     // 333

Each closure (shown in boldface) captures the same variable, i. (This actually makes sense when you consider that i is a variable whose value persists between loop iterations; you can even explicitly change i within the loop body if you want.) The consequence is that when the delegates are later invoked, each delegate sees i’s value at the time of invocation—which is 3. The solution, if we want to write 012, is to assign the iteration variable to a local variable that’s scoped inside the loop:

Action[] actions = new Action[3];
for (int i = 0; i < 3; i++)
{
    int loopScopedi = i;
    actions[i] = () => Console.Write (loopScopedi);
}
foreach (Action a in actions) a();     // 012

This causes the closure to capture a different variable on each iteration.

---

WARNING

foreach loops used to work in the same way but the rules have since changed. Starting with C# 5.0, you can safely close over a foreach loop’s iteration variable without needing a temporary variable.

---

Anonymous Methods

Anonymous methods are a C# 2.0 feature that has been mostly subsumed by lambda expressions. An anonymous method is like a lambda expression, except that it lacks implicitly typed parameters, expression syntax (an anonymous method must always be a statement block), and the ability to compile to an expression tree.
To write an anonymous method, you include the delegate keyword followed (optionally) by a parameter declaration and then a method body. For example, given this delegate:

```csharp
delegate int Transformer (int i);
```

we could write and call an anonymous method as follows:

```csharp
Transformer sqr = delegate (int x) {return x * x;};
Console.WriteLine (sqr(3));         // 9
```

The first line is semantically equivalent to the following lambda expression:

```csharp
Transformer sqr = (int x) => {return x * x;};
```

Or simply:

```csharp
Transformer sqr = x  => x * x;
```

A unique feature of anonymous methods is that you can omit the parameter declaration entirely—even if the delegate expects it. This can be useful in declaring events with a default empty handler:

```csharp
public event EventHandler Clicked = delegate { }; 
```

This avoids the need for a null check before firing the event. The following is also legal (notice the lack of parameters):

```csharp
Clicked += delegate { Console.Write ("clicked"); }; 
```

Anonymous methods capture outer variables in the same way lambda expressions do.

## try Statements and Exceptions

A `try` statement specifies a code block subject to error-handling or cleanup code. The `try` block must be followed by a `catch` block, a `finally` block, or both. The `catch` block executes when an error occurs in the `try` block. The `finally` block executes after execution leaves the `try` block (or if present, the `catch` block), to perform cleanup code, whether or not an error occurred.
A catch block has access to an Exception object that contains information about the error. You use a catch block to either compensate for the error or rethrow the exception. You rethrow an exception if you merely want to log the problem, or if you want to rethrow a new, higher-level exception type.

A finally block adds determinism to your program, by always executing no matter what. It’s useful for cleanup tasks such as closing network connections.

A try statement looks like this:

```csharp
try
{
    ... // exception may get thrown within execution of
    // this block
}
catch (ExceptionA ex)
{
    ... // handle exception of type ExceptionA
}
catch (ExceptionB ex)
{
    ... // handle exception of type ExceptionB
}
finally
{
    ... // cleanup code
}
```

Consider the following code:

```csharp
int x = 3, y = 0;
Console.WriteLine (x / y);
```

Because y is zero, the runtime throws a DivideByZeroException, and our program terminates. We can prevent this by catching the exception as follows:

```csharp
try
{
    int x = 3, y = 0;
    Console.WriteLine (x / y);
}
catch (DivideByZeroException ex)
{
    Console.Write ("y cannot be zero. ");
}
NOTE

This is a simple example to illustrate exception handling. We could deal with this particular scenario better in practice by checking explicitly for the divisor being zero before calling Calc.

Exceptions are relatively expensive to handle, taking hundreds of clock cycles.

When an exception is thrown, the CLR performs a test:

*Is execution currently within a try statement that can catch the exception?*

- If so, execution is passed to the compatible catch block. If the catch block successfully finishes executing, execution moves to the next statement after the try statement (if present, executing the finally block first).
- If not, execution jumps back to the caller of the function, and the test is repeated (after executing any finally blocks that wrap the statement).

If no function in the call stack takes responsibility for the exception, an error dialog is displayed to the user, and the program terminates.

**The catch Clause**

A catch clause specifies what type of exception to catch. This must either be System.Exception or a subclass of System.Exception. Catching System.Exception catches all possible errors. This is useful when:

- Your program can potentially recover regardless of the specific exception type.
• You plan to rethrow the exception (perhaps after logging it).
• Your error handler is the last resort, prior to termination of the program.

More typically, though, you catch specific exception types, in order to avoid having to deal with circumstances for which your handler wasn’t designed (e.g., an OutOfMemoryException).

You can handle multiple exception types with multiple `catch` clauses:

```csharp
try
{
    DoSomething();
}
catch (IndexOutOfRangeException ex) { ... }
catch (FormatException ex)          { ... }
catch (OverflowException ex)        { ... }
```

Only one `catch` clause executes for a given exception. If you want to include a safety net to catch more general exceptions (such as `System.Exception`) you must put the more specific handlers first.

An exception can be caught without specifying a variable, if you don’t need to access its properties:

```csharp
    catch (StackOverflowException)   // no variable
        { ... }
```

Furthermore, you can omit both the variable and the type (meaning that all exceptions will be caught):

```csharp
    catch { ... }
```

## The finally Block

A `finally` block always executes—whether or not an exception is thrown and whether or not the `try` block runs to completion. `finally` blocks are typically used for cleanup code.

A `finally` block executes either:

• After a `catch` block finishes
• After control leaves the try block because of a jump statement (e.g., return or goto)
• After the try block ends

A finally block helps add determinism to a program. In the following example, the file that we open always gets closed, regardless of whether:

• The try block finishes normally.
• Execution returns early because the file is empty (EndOfStream).
• An IOException is thrown while reading the file.

For example:

```csharp
static void ReadFile()
{
    StreamReader reader = null; // In System.IO namespace
    try
    {
        reader = File.OpenText("file.txt");
        if (reader.EndOfStream) return;
        Console.WriteLine(reader.ReadToEnd());
    }
    finally
    {
        if (reader != null) reader.Dispose();
    }
}
```

In this example, we closed the file by calling Dispose on the StreamReader. Calling Dispose on an object, within a finally block, is a standard convention throughout the .NET Framework and is supported explicitly in C# through the using statement.

The using statement

Many classes encapsulate unmanaged resources, such as file handles, graphics handles, or database connections. These classes implement System.IDisposable, which defines a single parameterless method named Dispose to clean up these resources. The using statement provides an elegant syntax for
calling Dispose on an IDisposable object within a finally block.

The following:

```csharp
using (StreamReader reader = File.OpenText("file.txt"))
{
...
}
```

is precisely equivalent to:

```csharp
StreamReader reader = File.OpenText("file.txt");
try
{
...
}
finally
{
  if (reader != null) ((IDisposable)reader).Dispose();
}
```

### Throwing Exceptions

Exceptions can be thrown either by the runtime or in user code. Here, Display throws a System.ArgumentNullException:

```csharp
static void Display (string name)
{
  if (name == null)
    throw new ArgumentNullException ("name");

  Console.WriteLine (name);
}
```

### Rethrowing an exception

You can capture and rethrow an exception as follows:

```csharp
try { ... } catch (Exception ex)
{
  // Log error
  ...
  throw;   // Rethrow same exception
}
```
Rethrowing in this manner lets you log an error without swallowing it. It also lets you back out of handling an exception should circumstances turn out to be outside what you expected.

**NOTE**
If we replaced `throw` with `throw ex`, the example would still work, but the `StackTrace` property of the exception would no longer reflect the original error.

The other common scenario is to rethrow a more specific or meaningful exception type:

```csharp
try {
    // parse a date of birth from XML element data
} catch (FormatException ex) {
    throw new XmlException("Invalid date of birth", ex);
}
```

When rethrowing a different exception, you can populate the `InnerException` property with the original exception to aid debugging. Nearly all types of exceptions provide a constructor for this purpose (such as in our example).

**Key Properties of System.Exception**

The most important properties of `System.Exception` are the following:

- **StackTrace**
  A string representing all the methods that are called from the origin of the exception to the `catch` block.

- **Message**
  A string with a description of the error.
InnerException
The inner exception (if any) that caused the outer exception. This, itself, may have another InnerException.

Common Exception Types
The following exception types are used widely throughout the CLR and the .NET Framework. You can throw them yourself or use them as base classes for deriving custom exception types.

System.ArgumentException
Thrown when a function is called with a bogus argument. This generally indicates a program bug.

SystemArgumentNullException
Subclass of ArgumentException that’s thrown when a function argument is (unexpectedly) null.

System.ArgumentOutOfRangeException
Subclass of ArgumentException that’s thrown when a (usually numeric) argument is too big or too small. For example, this is thrown when passing a negative number into a function that accepts only positive values.

System.InvalidOperationException
Thrown when the state of an object is unsuitable for a method to successfully execute, regardless of any particular argument values. Examples include reading an unopened file or getting the next element from an enumerator where the underlying list has been modified partway through the iteration.

System.NotSupportedException
Thrown to indicate that a particular functionality is not supported. A good example is calling the Add method on a collection for which IsReadOnly returns true.

System.NotImplementedException
Thrown to indicate that a function has not yet been implemented.
System.ObjectDisposedException
Thrown when the object upon which the function is called has been disposed.

---

**NOTE**
The need for ArgumentException (and its subclasses) is eliminated by code contracts, which are covered in Chapter 13 of *C# 5.0 in a Nutshell*.

---

**Enumeration and Iterators**

**Enumeration**

An *enumerator* is a read-only, forward-only cursor over a *sequence of values*; it is an object that implements `System.Collections.IEnumerator` or `System.Collections.Generic.IEnumerator<T>`.

The `foreach` statement iterates over an *enumerable* object. An enumerable object is the logical representation of a sequence. It is not itself a cursor, but an object that produces cursors over itself. An enumerable either implements `IEnumerable/IEnumerable<T>` or has a method named `GetEnumerator` that returns an *enumerator*.

The enumeration pattern is as follows:

```csharp
class Enumerator // Typically implements IEnumerator<T>
{
    public IteratorVariableType Current { get {...} }
    public bool MoveNext() {...}
}

class Enumerable // Typically implements IEnumerable<T>
{
    public Enumerator GetEnumerator() {...}
}
```

Here is the high-level way to iterate through the characters in the word *beer* using a `foreach` statement:
foreach (char c in "beer") Console.WriteLine (c);

Here is the low-level way to iterate through the characters in
beer without using a foreach statement:

```csharp
using (var enumerator = "beer".GetEnumerator())
    while (enumerator.MoveNext())
    {
        var element = enumerator.Current;
        Console.WriteLine (element);
    }
```

If the enumerator implements IDisposable, the foreach state-
ment also acts as a using statement, implicitly disposing the
enumerator object.

### Collection Initializers

You can instantiate and populate an enumerable object in a
single step. For example:

```csharp
using System.Collections.Generic;
...

List<int> list = new List<int> {1, 2, 3};
```

The compiler translates the last line into the following:

```csharp
List<int> list = new List<int>();
list.Add (1); list.Add (2); list.Add (3);
```

This requires that the enumerable object implements the
System.Collections.IEnumerable interface, and that it has an
Add method that has the appropriate number of parameters for
the call.

### Iterators

Whereas a foreach statement is a consumer of an enumerator,
an iterator is a producer of an enumerator. In this example, we
use an iterator to return a sequence of Fibonacci numbers
(where each number is the sum of the previous two):

```csharp
using System;
using System.Collections.Generic;
```
```csharp
class Test
{
    static void Main()
    {
        foreach (int fib in Fibs(6))
            Console.Write(fib + " ");
    }

    static IEnumerable<int> Fibs(int fibCount)
    {
        for (int i = 0, prevFib = 1, curFib = 1;
            i < fibCount;
            i++)
        {
            yield return prevFib;
            int newFib = prevFib + curFib;
            prevFib = curFib;
            curFib = newFib;
        }
    }
}
```

**OUTPUT:** 1 1 2 3 5 8

Whereas a `return` statement expresses, “Here’s the value you asked me to return from this method,” a `yield return` statement expresses, “Here’s the next element you asked me to yield from this enumerator.” On each `yield` statement, control is returned to the caller, but the callee’s state is maintained so that the method can continue executing as soon as the caller enumerates the next element. The lifetime of this state is bound to the enumerator, such that the state can be released when the caller has finished enumerating.
NOTE

The compiler converts iterator methods into private classes that implement `IEnumerable<T>` and/or `IEnumerator<T>`. The logic within the iterator block is “inverted” and spliced into the `MoveNext` method and the `Current` property on the compiler-written enumerator class, which effectively becomes a state machine. This means that when you call an iterator method, all you’re doing is instantiating the compiler-written class; none of your code actually runs! Your code runs only when you start enumerating over the resultant sequence, typically with a `foreach` statement.

Iterator Semantics

An iterator is a method, property, or indexer that contains one or more `yield` statements. An iterator must return one of the following four interfaces (otherwise, the compiler will generate an error):

- `System.Collections.IEnumerable`
- `System.Collections.IEnumerator`
- `System.Collections.Generic.IEnumerable<T>`
- `System.Collections.Generic.IEnumerator<T>`

Iterators that return an `enumerator` interface tend to be used less often. They’re useful when writing a custom collection class: typically, you name the iterator `GetEnumerator` and have your class implement `IEnumerable<T>`.

Iterators that return an `enumerable` interface are more common, and simpler to use because you don’t have to write a collection class. The compiler, behind the scenes, writes a private class implementing `IEnumerable<T>` (as well as `IEnumerator<T>`).

Multiple yield statements

An iterator can include multiple `yield` statements:
static void Main()
{
    foreach (string s in Foo())
        Console.Write (s + " ");    // One Two Three
}

static IEnumerable<string> Foo()
{
    yield return "One";
    yield return "Two";
    yield return "Three";
}

yield break

The yield break statement indicates that the iterator block should exit early, without returning more elements. We can modify Foo as follows to demonstrate:

static IEnumerable<string> Foo (bool breakEarly)
{
    yield return "One";
    yield return "Two";
    if (breakEarly) yield break;
    yield return "Three";
}

WARNING

A return statement is illegal in an iterator block—you must use yield break instead.

Composing Sequences

Iterators are highly composable. We can extend our Fibonacci example by adding the following method to the class:

static IEnumerable<int> EvenNumbersOnly (IEnumerable<int> sequence)
{
    foreach (int x in sequence)
        if ((x % 2) == 0)
            yield return x;
We can then output even Fibonacci numbers as follows:

```csharp
foreach (int fib in EvenNumbersOnly (Fibs (6)))
    Console.Write (fib + " "); // 2 8
```

Each element is not calculated until the last moment—when requested by a `MoveNext()` operation. Figure 5 shows the data requests and data output over time.

The composability of the iterator pattern is essential in building LINQ queries.
**Nullable Types**

Reference types can represent a nonexistent value with a null reference. Value types, however, cannot ordinarily represent null values. For example:

```csharp
    string s = null;   // OK - reference type.
    int i = null;      // Compile error - int cannot be null.
```

To represent null in a value type, you must use a special construct called a *nullable type*. A nullable type is denoted with a value type followed by the `?` symbol:

```csharp
    int? i = null;                     // OK - Nullable Type
    Console.WriteLine (i == null);     // True
```

### Nullable<T> Struct

`T?` translates into `System.Nullable<T>`. `Nullable<T>` is a lightweight immutable structure, having only two fields, to represent `Value` and `HasValue`. The essence of `System.Nullable<T>` is very simple:

```csharp
    public struct Nullable<T> where T : struct
    {
        public T Value {get;}
        public bool HasValue {get;}
        public T GetValueOrDefault();
        public T GetValueOrDefault (T defaultValue);
        ...
    }
```

The code:

```csharp
    int? i = null;
    Console.WriteLine (i == null);              // True
```

translates to:

```csharp
    Nullable<int> i = new Nullable<int>();
    Console.WriteLine (! i.HasValue);           // True
```

Attempting to retrieve `Value` when `HasValue` is false throws an `InvalidOperationException`. `GetValueOrDefault()` returns `Value` if `HasValue` is true; otherwise, it returns `new T()` or a specified custom default value.
The default value of \( T? \) is null.

**Nullable Conversions**

The conversion from \( T \) to \( T? \) is implicit, and from \( T? \) to \( T \) is explicit. For example:

```csharp
int? x = 5;        // implicit
int y = (int)x;    // explicit
```

The explicit cast is directly equivalent to calling the nullable object’s `Value` property. Hence, an `InvalidOperationException` is thrown if `HasValue` is false.

**Boxing/Unboxing Nullable Values**

When \( T? \) is boxed, the boxed value on the heap contains \( T \), not \( T? \). This optimization is possible because a boxed value is a reference type that can already express null.

C# also permits the unboxing of nullable types with the `as` operator. The result will be `null` if the cast fails:

```csharp
object o = "string";
int? x = o as int?;
Console.WriteLine (x.HasValue); // False
```

**Operator Lifting**

The `Nullable<T>` struct does not define operators such as `<`, `>`, or even `==`. Despite this, the following code compiles and executes correctly:

```csharp
int? x = 5;
int? y = 10;
bool b = x < y;       // true
```

This works because the compiler borrows or “lifts” the less-than operator from the underlying value type. Semantically, it translates the preceding comparison expression into this:

```csharp
bool b = (x.HasValue && y.HasValue)
    ? (x.Value < y.Value)
    : false;
```
In other words, if both \(x\) and \(y\) have values, it compares via int’s less-than operator; otherwise, it returns false.

Operator lifting means you can implicitly use \(T\)’s operators on \(T?\). You can define operators for \(T?\) in order to provide special-purpose null behavior, but in the vast majority of cases, it’s best to rely on the compiler automatically applying systematic nullable logic for you.

The compiler performs null logic differently depending on the category of operator.

**Equality operators (==, !=)**

Lifted equality operators handle nulls just like reference types do. This means two null values are equal:

```csharp
Console.WriteLine (null == null);  // True
Console.WriteLine ((bool?)null == (bool?)null);  // True
```

Further:

- If exactly one operand is null, the operands are unequal.
- If both operands are non-null, their Values are compared.

**Relational operators (<, <=, >=, >)**

The relational operators work on the principle that it is meaningless to compare null operands. This means comparing a null value to either a null or a non-null value returns false.

```csharp
bool b = x < y;  // Translation:
bool b = (x == null || y == null) ? false
            : (x.Value < y.Value);

// b is false (assuming x is 5 and y is null)
```

**All other operators (+, −, *, /, %, &,, |, &^, <<, >>, +, ++, --, !, ~)**

These operators return null when any of the operands are null. This pattern should be familiar to SQL users.

```csharp
int? c = x + y;  // Translation:
```
int? c = (x == null || y == null)
    ? null
    : (int?) (x.Value + y.Value);

    // c is null (assuming x is 5 and y is null)

An exception is when the & and | operators are applied to bool?, which we will discuss shortly.

**Mixing nullable and non-nullable operators**

You can mix and match nullable and non-nullable types (this works because there is an implicit conversion from T to T?):

```csharp
int? a = null;
int b = 2;
int? c = a + b;   // c is null - equivalent to a + (int?)b
```

**bool? with & and | Operators**

When supplied operands of type bool?, the & and | operators treat null as an unknown value. So, null | true is true, because:

- If the unknown value is false, the result would be true.
- If the unknown value is true, the result would be true.

Similarly, null & false is false. This behavior would be familiar to SQL users. The following example enumerates other combinations:

```csharp
bool? n = null, f = false, t = true;
Console.WriteLine (n | n);    // (null)
Console.WriteLine (n | f);    // (null)
Console.WriteLine (n | t);    // True
Console.WriteLine (n & n);    // (null)
Console.WriteLine (n & f);    // False
Console.WriteLine (n & t);    // (null)
```

**Null Coalescing Operator**

The ?? operator is the null coalescing operator, and it can be used with both nullable types and reference types. It says, “If the operand is non-null, give it to me; otherwise, give me a default value.” For example:
int? x = null;
int y = x ?? 5;        // y is 5

int? a = null, b = 1, c = 2;
Console.Write (a ?? b ?? c);  // 1 (first non-null value)

The ?? operator is equivalent to calling GetValueOrDefault with an explicit default value, except that the expression passed to GetValueOrDefault is never evaluated if the variable is not null.

**Operator Overloading**

Operators can be overloaded to provide more natural syntax for custom types. Operator overloading is most appropriately used for implementing custom structs that represent fairly primitive data types. For example, a custom numeric type is an excellent candidate for operator overloading.

The following symbolic operators can be overloaded:

```
+   -   *   /   ++   --   !   ~   %   &   |   ^
==  !=  <   <<  >>   >
```

Implicit and explicit conversions can also be overridden (with the implicit and explicit keywords), as can the literals true and false, and the unary + and - operators.

The compound assignment operators (e.g., +=, /=) are automatically overridden when you override the noncompound operators (e.g., +, /).

**Operator Functions**

An operator is overloaded by declaring an operator function. An operator function must be static, and at least one of the operands must be the type in which the operator function is declared.

In the following example, we define a struct called Note representing a musical note, and then overload the + operator:
public struct Note
{
    int value;

    public Note (int semitonesFromA)
    { value = semitonesFromA; }

    public static Note operator + (Note x, int semitones)
    {
        return new Note (x.value + semitones);
    }
}

This overload allows us to add an int to a Note:

Note B = new Note (2);
Note CSharp = B + 2;

Since we overrode +, we can use += too:

CSharp += 2;

**Overloading Equality and Comparison Operators**

Equality and comparison operators are often overridden when writing structs, and in rare cases with classes. Special rules and obligations come with overloading these operators:

*Pairing*

The C# compiler enforces that operators that are logical pairs are both defined. These operators are (== !=), (< >), and (<= >=).

*Equals and GetHashCode*

If you overload == and !=, you will usually need to override object’s Equals and GetHashCode methods so that collections and hashables will work reliably with the type.

*IComparable and IComparable<T>*

If you overload < and >, you would also typically implement IComparable and IComparable<T>.

Extending the previous example, here’s how we could overload Note’s equality operators:
### Custom Implicit and Explicit Conversions

Implicit and explicit conversions are overloadable operators. These conversions are typically overloaded to make converting between strongly related types (such as numeric types) concise and natural.

As explained in the discussion on types, the rationale behind implicit conversions is that they should always succeed and not lose information during conversion. Otherwise, explicit conversions should be defined.

In the following example, we define conversions between our musical `Note` type and a `double` (which represents the frequency in hertz of that note):

```csharp
// Convert to hertz
public static implicit operator double (Note x)
{
    return 440 * Math.Pow (2,(double) x.value / 12 );
}

// Convert from hertz (accurate to nearest semitone)
public static explicit operator Note (double x)
{
    return new Note ((int) (0.5 + 12 * (Math.Log(x/440)
```
/ Math.Log(2) ));
}
...

Note n = (Note)554.37; // explicit conversion
double x = n; // implicit conversion

---

**NOTE**

This example is somewhat contrived: in a real-life situation, these conversions might be better implemented with a ToFrequency method and a (static) FromFrequency method.

Custom conversions are ignored by the as and is operators.

---

**Extension Methods**

*Extension methods* allow an existing type to be extended with new methods, without altering the definition of the original type. An extension method is a static method of a static class, where the this modifier is applied to the first parameter. The type of the first parameter will be the type that is extended. For example:

```csharp
public static class StringHelper
{
    public static bool IsCapitalized (this string s)
    {
        if (string.IsNullOrEmpty(s)) return false;
        return char.IsUpper(s[0]);
    }
}
```

The IsCapitalized extension method can be called as though it were an instance method on a string, as follows:

```
Console.Write ("Perth".IsCapitalized());
```

An extension method call, when compiled, is translated back into an ordinary static method call:

```
Console.Write (StringHelper.IsCapitalized ("Perth"));
```
Interfaces can be extended, too:

```csharp
public static T First<T> (this IEnumerable<T> sequence) {
    foreach (T element in sequence)
        return element;
    throw new InvalidOperationException ("No elements!");
}
...
Console.WriteLine ("Seattle".First());   // S
```

### Extension Method Chaining

Extension methods, like instance methods, provide a tidy way to chain functions. Consider the following two functions:

```csharp
public static class StringHelper {
    public static string Pluralize (this string s) {...}
    public static string Capitalize (this string s) {...}
}
```

x and y are equivalent and both evaluate to "Sausages", but x uses extension methods, whereas y uses static methods:

```csharp
string x = "sausage".Pluralize().Capitalize();
string y = StringHelper.Capitalize
            (StringHelper.Pluralize ("sausage"));
```

### Ambiguity and Resolution

#### Namespaces

An extension method cannot be accessed unless the namespace is in scope (typically imported with a `using` statement).

#### Extension methods versus instance methods

Any compatible instance method will always take precedence over an extension method—even when the extension method’s parameters are more specifically type-matched.
Extension methods versus extension methods

If two extension methods have the same signature, the extension method must be called as an ordinary static method to disambiguate the method to call. If one extension method has more specific arguments, however, the more specific method takes precedence.

Anonymous Types

An anonymous type is a simple class created on the fly to store a set of values. To create an anonymous type, you use the new keyword followed by an object initializer, specifying the properties and values the type will contain. For example:

```csharp
var dude = new { Name = "Bob", Age = 1 };  
```

The compiler resolves this by writing a private nested type with read-only properties for Name (type string) and Age (type int). You must use the var keyword to reference an anonymous type, because the type’s name is compiler-generated.

The property name of an anonymous type can be inferred from an expression that is itself an identifier. For example:

```csharp
int Age = 1;  
var dude = new { Name = "Bob", Age };  
```

is equivalent to:

```csharp
var dude = new { Name = "Bob", Age = Age };  
```

You can create arrays of anonymous types as follows:

```csharp
var dudes = new[]  
{
    new { Name = "Bob", Age = 30 },  
    new { Name = "Mary", Age = 40 }  
};  
```

Anonymous types are used primarily when writing LINQ queries.
LINQ

LINQ, or Language Integrated Query, allows you to write structured type-safe queries over local object collections and remote data sources.

LINQ lets you query any collection implementing IEnumera\*ble<>\*, whether an array, list, XML DOM, or remote data source (such as a table in SQL Server). LINQ offers the benefits of both compile-time type checking and dynamic query composition.

**NOTE**

A good way to experiment with LINQ is to download LINQPad at [http://www.linqpad.net](http://www.linqpad.net). LINQPad lets you interactively query local collections and SQL databases in LINQ without any setup and is preloaded with numerous examples.

LINQ Fundamentals

The basic units of data in LINQ are sequences and elements. A sequence is any object that implements the generic IEnumera\*ble interface, and an element is each item in the sequence. In the following example, names is a sequence, and Tom, Dick, and Harry are elements:

```csharp
string[] names = { "Tom", "Dick", "Harry" };
```

We call a sequence such as this a local sequence because it represents a local collection of objects in memory.

A query operator is a method that transforms a sequence. A typical query operator accepts an input sequence and emits a transformed output sequence. In the Enumerable class in System.Linq, there are around 40 query operators; all implemented as static extension methods. These are called standard query operators.
NOTE
LINQ also supports sequences that can be dynamically fed from a remote data source such as SQL Server. These sequences additionally implement the IQueryable<> interface and are supported through a matching set of standard query operators in the Queryable class.

A simple query
A query is an expression that transforms sequences with one or more query operators. The simplest query comprises one input sequence and one operator. For instance, we can apply the Where operator on a simple array to extract those names whose length is at least four characters as follows:

```csharp
string[] names = { "Tom", "Dick", "Harry" };

IEnumerable<string> filteredNames =
    System.Linq.Enumerable.Where (names, n => n.Length >= 4);

foreach (string n in filteredNames)
    Console.Write (n + "|");             // Dick|Harry|
```

Because the standard query operators are implemented as extension methods, we can call Where directly on names—as though it were an instance method:

```csharp
IEnumerable<string> filteredNames =
    names.Where (n => n.Length >= 4);
```

(For this to compile, you must import the System.Linq namespace with a using directive.) The Where method in System.Linq.Enumerable has the following signature:

```csharp
static IEnumerable<TSource> Where<TSource> (this IEnumerable<TSource> source,
    Func<TSource,bool> predicate)
```

source is the input sequence; predicate is a delegate that is invoked on each input element. The Where method includes all elements in the output sequence, for which the delegate returns
true. Internally, it’s implemented with an iterator—here’s its source code:

```csharp
foreach (TSource element in source)
    if (predicate (element))
        yield return element;
```

### Projecting

Another fundamental query operator is the Select method. This transforms (projects) each element in the input sequence with a given lambda expression:

```csharp
string[] names = { "Tom", "Dick", "Harry" };

IEnumerable<string> upperNames =
    names.Select (n => n.ToUpper());

foreach (string n in upperNames)
    Console.Write (n + "|");       // TOM|DICK|HARRY|
```

A query can project into an anonymous type:

```csharp
var query = names.Select (n => new {
    Name = n,
    Length = n.Length
});
```

```csharp
foreach (var row in query)
    Console.WriteLine (row);
```

Here’s the result:

```csharp
{ Name = Tom, Length = 3 }
{ Name = Dick, Length = 4 }
{ Name = Harry, Length = 5 }
```

### Take and Skip

The original ordering of elements within an input sequence is significant in LINQ. Some query operators rely on this behavior, such as Take, Skip, and Reverse. The Take operator outputs the first $x$ elements, discarding the rest:

```csharp
int[] numbers  = { 10, 9, 8, 7, 6 };
IEnumerable<int> firstThree = numbers.Take (3);
// firstThree is { 10, 9, 8 }
```
The `Skip` operator ignores the first \( x \) elements, and outputs the rest:

\[
\text{IEnumerable<int> lastTwo = numbers.Skip(3);}\
\]

**Element operators**

Not all query operators return a sequence. The *element* operators extract one element from the input sequence; examples are `First`, `Last`, `Single`, and `ElementAt`:

```csharp
int[] numbers = { 10, 9, 8, 7, 6 };
int firstNumber = numbers.First(); // 10
int lastNumber = numbers.Last(); // 6
int secondNumber = numbers.ElementAt(2); // 8
int firstOddNum = numbers.First(n => n % 2 == 1); // 9
```

All of these operators throw an exception if no elements are present. To get a null/empty return value instead of an exception, use `FirstOrDefault`, `LastOrDefault`, `SingleOrDefault`, or `ElementAtOrDefault`.

The `Single` and `SingleOrDefault` methods are equivalent to `First` and `FirstOrDefault` except that they throw an exception if there’s more than one match. This behavior is useful when querying a database table for a row by primary key.

**Aggregation operators**

The *aggregation* operators return a scalar value; usually of numeric type. The most commonly used aggregation operators are `Count`, `Min`, `Max`, and `Average`:

```csharp
int[] numbers = { 10, 9, 8, 7, 6 };
int count = numbers.Count(); // 5
int min = numbers.Min(); // 6
int max = numbers.Max(); // 10
double avg = numbers.Average(); // 8
```

`Count` accepts an optional predicate, which indicates whether to include a given element. The following counts all even numbers:

```csharp
int evenNums = numbers.Count(n => n % 2 == 0); // 3
```
The `Min`, `Max`, and `Average` operators accept an optional argument that transforms each element prior to it being aggregated:

```csharp
int maxRemainderAfterDivBy5 = numbers.Max
    (n => n % 5); // 4
```

The following calculates the root-mean-square of `numbers`:

```csharp
double rms = Math.Sqrt (numbers.Average (n => n * n));
```

**Quantifiers**

The quantifiers return a `bool` value. The quantifiers are as follows: `Contains`, `Any`, `All`, and `SequenceEquals` (which compares two sequences):

```csharp
int[] numbers = { 10, 9, 8, 7, 6 };

bool hasTheNumberNine = numbers.Contains (9); // true
bool hasMoreThanZeroElements = numbers.Any(); // true
bool hasOddNum = numbers.Any (n => n % 2 == 1); // true
bool allOddNums = numbers.All (n => n % 2 == 1); // false
```

**Set operators**

The `set` operators accept two same-typed input sequences. `Concat` appends one sequence to another; `Union` does the same but with duplicates removed:

```csharp
int[] seq1 = { 1, 2, 3 }, seq2 = { 3, 4, 5 };

IEnumerable<int>
concat = seq1.Concat (seq2), // { 1, 2, 3, 3, 4, 5 }
union  = seq1.Union  (seq2),  // { 1, 2, 3, 4, 5 }
```

The other two operators in this category are `Intersect` and `Except`:

```csharp
IEnumerable<int>
commonality = seq1.Intersect (seq2), // { 3 }
difference1 = seq1.Except    (seq2),    // { 1, 2 }
difference2 = seq2.Except    (seq1);    // { 4, 5 }
```
Deferred Execution

An important feature of many query operators is that they execute not when constructed, but when *enumerated* (in other words, when `MoveNext` is called on its enumerator). Consider the following query:

```csharp
var numbers = new List<int> { 1 };
numbers.Add (1);

IEnumerable<int> query = numbers.Select (n => n * 10);
numbers.Add (2);    // Sneak in an extra element

foreach (int n in query)
    Console.Write (n + "|");          // 10|20|
```

The extra number that we sneaked into the list *after* constructing the query is included in the result, because it’s not until the `foreach` statement runs that any filtering or sorting takes place. This is called *deferred* or *lazy* evaluation. Deferred execution decouples query *construction* from query *execution*, allowing you to construct a query in several steps, as well as making it possible to query a database without retrieving all the rows to the client. All standard query operators provide deferred execution, with the following exceptions:

- Operators that return a single element or scalar value (the *element operators*, *aggregation operators*, and *quantifiers*)
- The following *conversion* operators:
  - `ToArray`, `ToList`, `ToDictionary`, `ToLookup`

The conversion operators are handy, in part, because they defeat lazy evaluation. This can be useful to “freeze” or cache the results at a certain point in time, to avoid reexecuting a computationally intensive or remotely sourced query such as a LINQ to SQL table. (A side effect of lazy evaluation is that the query gets reevaluated should you later reenumerate it.)

The following example illustrates the `ToList` operator:
var numbers = new List<int>() { 1, 2 };

List<int> timesTen = numbers
    .Select (n => n * 10)
    .ToList();    // Executes immediately into a List<int>

numbers.Clear();
Console.WriteLine (timesTen.Count);      // Still 2

---

**WARNING**

Subqueries provide another level of indirection. Everything in a subquery is subject to deferred execution—including aggregation and conversion methods, because the subquery is itself executed only lazily upon demand. Assuming names is a string array, a subquery looks like this:

```csharp
names.Where (n => n.Length == names.Min (n2 => n2.Length))
```

---

**Standard Query Operators**

It is possible to divide the standard query operators (as implemented in the `System.Linq.Enumerable` class) into 12 categories, summarized in Table 1.

*Table 1. Query operator categories*

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Deferred execution?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filtering</td>
<td>Returns a subset of elements that satisfy a given condition</td>
<td>Yes</td>
</tr>
<tr>
<td>Projecting</td>
<td>Transforms each element with a lambda function, optionally expanding subsequences</td>
<td>Yes</td>
</tr>
<tr>
<td>Joining</td>
<td>Meshes elements of one collection with another, using a time-efficient lookup strategy</td>
<td>Yes</td>
</tr>
<tr>
<td>Ordering</td>
<td>Returns a reordering of a sequence</td>
<td>Yes</td>
</tr>
<tr>
<td>Grouping</td>
<td>Groups a sequence into subsequences</td>
<td>Yes</td>
</tr>
</tbody>
</table>

---

148  | C# 5.0 Pocket Reference
<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Deferred execution?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set</td>
<td>Accepts two same-typed sequences, and returns their commonality, sum, or difference</td>
<td>Yes</td>
</tr>
<tr>
<td>Element</td>
<td>Picks a single element from a sequence</td>
<td>No</td>
</tr>
<tr>
<td>Aggregation</td>
<td>Performs a computation over a sequence, returning a scalar value (typically a number)</td>
<td>No</td>
</tr>
<tr>
<td>Quantification</td>
<td>Performs a computation over a sequence, returning true or false</td>
<td>No</td>
</tr>
<tr>
<td>Conversion: Import</td>
<td>Converts a nongeneric sequence to a (queryable) generic sequence</td>
<td>Yes</td>
</tr>
<tr>
<td>Conversion: Export</td>
<td>Converts a sequence to an array, list, dictionary, or lookup, forcing immediate evaluation</td>
<td>No</td>
</tr>
<tr>
<td>Generation</td>
<td>Manufactures a simple sequence</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 2 through Table 13 summarize each query operator. The operators shown in bold have special support in C# (see “Query Expressions” on page 153).

**Table 2. Filtering operators**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where</td>
<td>Returns a subset of elements that satisfy a given condition</td>
</tr>
<tr>
<td>Take</td>
<td>Returns the first $x$ elements, and discards the rest</td>
</tr>
<tr>
<td>Skip</td>
<td>Ignores the first $x$ elements, and returns the rest</td>
</tr>
<tr>
<td>TakeWhile</td>
<td>Emits elements from the input sequence until the given predicate is true</td>
</tr>
<tr>
<td>SkipWhile</td>
<td>Ignores elements from the input sequence until the given predicate is true, and then emits the rest</td>
</tr>
<tr>
<td>Distinct</td>
<td>Returns a collection that excludes duplicates</td>
</tr>
</tbody>
</table>

**Table 3. Projection operators**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select</td>
<td>Transforms each input element with a given lambda expression</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>SelectMany</td>
<td>Transforms each input element, then flattens and concatenates the resultant subsequences</td>
</tr>
</tbody>
</table>

**Table 4. Joining operators**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Join</td>
<td>Applies a lookup strategy to match elements from two collections, emitting a flat result set</td>
</tr>
<tr>
<td>GroupJoin</td>
<td>As above, but emits a <em>hierarchical</em> result set</td>
</tr>
<tr>
<td>Zip</td>
<td>Enumerates two sequences in step, returning a sequence that applies a function over each element pair</td>
</tr>
</tbody>
</table>

**Table 5. Ordering operators**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OrderBy, ThenBy</td>
<td>Returns the elements sorted in ascending order</td>
</tr>
<tr>
<td>OrderByDescending, ThenByDescending</td>
<td>Returns the elements sorted in descending order</td>
</tr>
<tr>
<td>Reverse</td>
<td>Returns the elements in reverse order</td>
</tr>
</tbody>
</table>

**Table 6. Grouping operators**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GroupBy</td>
<td>Groups a sequence into subsequences</td>
</tr>
</tbody>
</table>

**Table 7. Set operators**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concat</td>
<td>Concatenates two sequences</td>
</tr>
<tr>
<td>Union</td>
<td>Concatenates two sequences, removing duplicates</td>
</tr>
<tr>
<td>Intersect</td>
<td>Returns elements present in both sequences</td>
</tr>
<tr>
<td>Except</td>
<td>Returns elements present in the first, but not the second sequence</td>
</tr>
</tbody>
</table>
Table 8. Element operators

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>First, FirstOrDefault</td>
<td>Returns the first element in the sequence, or the first element satisfying a given predicate</td>
</tr>
<tr>
<td>Last, LastOrDefault</td>
<td>Returns the last element in the sequence, or the last element satisfying a given predicate</td>
</tr>
<tr>
<td>Single, SingleOrDefault</td>
<td>Equivalent to First/FirstOrDefault, but throws an exception if there is more than one match</td>
</tr>
<tr>
<td>ElementAt, ElementAtOrDefault</td>
<td>Returns the element at the specified position</td>
</tr>
<tr>
<td>DefaultIfEmpty</td>
<td>Returns a single-value sequence whose value is null or default(TSource) if the sequence has no elements</td>
</tr>
</tbody>
</table>

Table 9. Aggregation operators

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count, LongCount</td>
<td>Returns the total number of elements in the input sequence, or the number of elements satisfying a given predicate</td>
</tr>
<tr>
<td>Min, Max</td>
<td>Returns the smallest or largest element in the sequence</td>
</tr>
<tr>
<td>Sum, Average</td>
<td>Calculates a numeric sum or average over elements in the sequence</td>
</tr>
<tr>
<td>Aggregate</td>
<td>Performs a custom aggregation</td>
</tr>
</tbody>
</table>

Table 10. Qualifiers

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contains</td>
<td>Returns true if the input sequence contains the given element</td>
</tr>
<tr>
<td>Any</td>
<td>Returns true if any elements satisfy the given predicate</td>
</tr>
<tr>
<td>All</td>
<td>Returns true if all elements satisfy the given predicate</td>
</tr>
<tr>
<td>SequenceEqual</td>
<td>Returns true if the second sequence has identical elements to the input sequence</td>
</tr>
</tbody>
</table>
Table 11. Conversion operators (import)

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OfType</td>
<td>Converts IEnumerable to IEnumerable&lt;T&gt;, discarding wrongly typed elements</td>
</tr>
<tr>
<td>Cast</td>
<td>Converts IEnumerable to IEnumerable&lt;T&gt;, throwing an exception if there are any wrongly typed elements</td>
</tr>
</tbody>
</table>

Table 12. Conversion operators (export)

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ToArray</td>
<td>Converts IEnumerable&lt;T&gt; to T[]</td>
</tr>
<tr>
<td>ToList</td>
<td>Converts IEnumerable&lt;T&gt; to List&lt;T&gt;</td>
</tr>
<tr>
<td>ToDictionary</td>
<td>Converts IEnumerable&lt;T&gt; to Dictionary&lt;TKey,TValue&gt;</td>
</tr>
<tr>
<td>ToLookup</td>
<td>Converts IEnumerable&lt;T&gt; to ILookup&lt;TKey,TElement&gt;</td>
</tr>
<tr>
<td>AsEnumerable</td>
<td>Downcasts to IEnumerable&lt;T&gt;</td>
</tr>
<tr>
<td>AsQueryable</td>
<td>Casts or converts to IQueryable&lt;T&gt;</td>
</tr>
</tbody>
</table>

Table 13. Generation operators

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty</td>
<td>Creates an empty sequence</td>
</tr>
<tr>
<td>Repeat</td>
<td>Creates a sequence of repeating elements</td>
</tr>
<tr>
<td>Range</td>
<td>Creates a sequence of integers</td>
</tr>
</tbody>
</table>

Chaining Query Operators

To build more complex queries, you chain query operators together. For example, the following query extracts all strings containing the letter a, sorts them by length, and then converts the results to uppercase:

```csharp
string[] names = { "Tom","Dick","Harry","Mary","Jay" };

IEnumerable&lt;string&gt; query = names
    .Where (n => n.Contains ("a"))
    .OrderBy (n => n.Length)
    .Select  (n => n.ToUpper());
```
foreach (string name in query)
    Console.Write (name + "|");

// RESULT: JAY|MARY|HARRY|

Where, OrderBy, and Select are all standard query operators that resolve to extension methods in the Enumerable class. The Where operator emits a filtered version of the input sequence; OrderBy emits a sorted version of its input sequence; Select emits a sequence where each input element is transformed or projected with a given lambda expression (n.ToUpper(), in this case). Data flows from left to right through the chain of operators, so the data is first filtered, then sorted, then projected. The end result resembles a production line of conveyor belts, as illustrated in Figure 6.

Deferred execution is honored throughout with operators, so no filtering, sorting, or projecting takes place until the query is actually enumerated.

**Query Expressions**

So far, we’ve written queries by calling extension methods in the Enumerable class. In this book, we describe this as fluent syntax. C# also provides special language support for writing queries, called query expressions. Here’s the preceding query expressed as a query expression:
A query expression always starts with a `from` clause, and ends with either a `select` or `group` clause. The `from` clause declares a `range variable` (in this case, `n`) which you can think of as traversing the input collection—rather like `foreach`. Figure 7 illustrates the complete syntax.
NOTE

If you’re familiar with SQL, LINQ’s query expression syntax—with the `from` clause first and the `select` clause last—might look bizarre. Query expression syntax is actually more logical because the clauses appear in the order they’re executed. This allows Visual Studio to prompt you with IntelliSense as you type, as well as simplifying the scoping rules for subqueries.

The compiler processes query expressions by translating them to fluent syntax. It does this in a fairly mechanical fashion—much like it translates `foreach` statements into calls to `GetEnumerator` and `MoveNext`:

```csharp
IEnumerable<string> query = names
    .Where (n => n.Contains ("a"))
    .OrderBy (n => n.Length)
    .Select (n => n.ToUpper());
```

The `Where`, `OrderBy`, and `Select` operators then resolve using the same rules that would apply if the query were written in fluent syntax. In this case, they bind to extension methods in the `Enumerable` class (assuming you’ve imported the `System.Linq` namespace) because `names` implements `IEnumerable<string>`. The compiler doesn’t specifically favor the `Enumerable` class, however, when translating query syntax. You can think of the compiler as mechanically injecting the words `Where`, `OrderBy`, and `Select` into the statement, and then compiling it as though you’d typed the method names yourself. This offers flexibility in how they resolve—the operators in LINQ to SQL and Entity Framework queries, for instance, bind instead to the extension methods in the `Queryable` class.

**Query expressions versus fluent queries**

Query expressions and fluent queries each have advantages.

Query expressions support only a small subset of query operators, namely:
Where, Select, SelectMany
OrderBy, ThenBy, OrderByDescending, ThenByDescending
GroupBy, Join, GroupJoin

For queries that use other operators, you must either write entirely in fluent syntax or construct mixed-syntax queries, for instance:

```csharp
string[] names = { "Tom","Dick","Harry","Mary","Jay" };

IEnumerable<string> query =
    from n in names
    where n.Length == names.Min (n2 => n2.Length)
    select n;
```

This query returns names whose length matches that of the shortest ("Tom" and "Jay"). The subquery (in bold) calculates the minimum length of each name, and evaluates to 3. We have to use fluent syntax for the subquery, because the `Min` operator has no support in query expression syntax. We can, however, still use query syntax for the outer query.

The main advantage of query syntax is that it can radically simplify queries that involve the following:

- A `let` clause for introducing a new variable alongside the range variable
- Multiple generators (`SelectMany`) followed by an outer range variable reference
- A `Join` or `GroupJoin` equivalent, followed by an outer range variable reference

### The let Keyword

The `let` keyword introduces a new variable alongside the range variable. For instance, suppose we want to list all names whose length, without vowels, is greater than two characters:

```csharp
string[] names = { "Tom","Dick","Harry","Mary","Jay" };

IEnumerable<string> query =
    from n in names
    let vowelless = Regex.Replace (n, "[aeiou]", "")
    where vowelless.Length > 2
    select n;
```
orderby vowelless
select n + " - " + vowelless;

The output from enumerating this query is:

Dick - Dck
Harry - Hrry
Mary - Mry

The let clause performs a calculation on each element, without losing the original element. In our query, the subsequent clauses (where, orderby, and select) have access to both n and vowelless. A query can include any multiple let clauses, and they can be interspersed with additional where and join clauses.

The compiler translates the let keyword by projecting into a temporary anonymous type that contains both the original and transformed elements:

```csharp
IEnumerable<string> query = names
    .Select (n => new
    {
        n = n,
        vowelless = Regex.Replace (n, "[aeiou]","")
    })
    .Where (temp0 => (temp0.vowelless.Length > 2))
    .OrderBy (temp0 => temp0.vowelless)
    .Select (temp0 => ((temp0.n + " - ") + temp0.vowelless))
```

**Query Continuations**

If you want to add clauses after a select or group clause, you must use the into keyword to “continue” the query. For instance:

```csharp
from c in "The quick brown tiger".Split()
select c.ToUpper() into upper
where upper.StartsWith ("T")
select upper

// RESULT: "THE", "TIGER"
```

Following an into clause, the previous range variable is out of scope.
The compiler translates queries with an `into` keyword simply into a longer chain of operators:

```csharp
"The quick brown tiger".Split()
  .Select (c => c.ToUpper())
  .Where (upper => upper.StartsWith ("T"))
```

(It omits the final `Select(upper=>upper)` because it’s redundant.)

Multiple Generators

A query can include multiple generators (`from` clauses). For example:

```csharp
int[] numbers = { 1, 2, 3 }
string[] letters = { "a", "b" }

IEnumerable<string> query = from n in numbers
  from l in letters
  select n.ToString() + l;
```

The result is a cross product, rather like you’d get with nested `foreach` loops:

"1a", "1b", "2a", "2b", "3a", "3b"

When there’s more than one `from` clause in a query, the compiler emits a call to `SelectMany`:

```csharp
IEnumerable<string> query = numbers.SelectMany (n => letters,
  (n, l) => (n.ToString() + l));
```

`SelectMany` performs nested looping. It enumerates every element in the source collection (`numbers`), transforming each element with the first lambda expression (`letters`). This generates a sequence of subsequeces, which it then enumerates. The final output elements are determined by the second lambda expression (`n.ToString()+l`).

If you subsequently apply a `where` clause, you can filter the cross product and project a result akin to a `join`:

```csharp
string[] players = { "Tom", "Jay", "Mary" };
```
IEnumerable<string> query =
    from name1 in players
    from name2 in players
    where name1.CompareTo(name2) < 0
    orderby name1, name2
    select name1 + " vs " + name2;

RESULT: { "Jay vs Mary", "Jay vs Tom", "Mary vs Tom" }

The translation of this query into fluent syntax is more complex, requiring a temporary anonymous projection. The ability to perform this translation automatically is one of the key benefits of query expressions.

The expression in the second generator is allowed to use the first range variable:

    string[] fullNames =
    { "Anne Williams", "John Fred Smith", "Sue Green" };

    IEnumerable<string> query =
        from fullName in fullNames
        from name in fullName.Split()
        select name + " came from " + fullName;

    Anne came from Anne Williams
    Williams came from Anne Williams
    John came from John Fred Smith

This works because the expression fullName.Split emits a sequence (an array of strings).

Multiple generators are used extensively in database queries, to flatten parent-child relationships and to perform manual joins.

**Joining**

LINQ provides three joining operators, the main ones being Join and GroupJoin which perform keyed lookup-based joins. Join and GroupJoin support only a subset of the functionality you get with multiple generators/SelectMany, but are more performant with local queries because they use a hashtable-based lookup strategy rather than performing nested loops.
(With LINQ to SQL and Entity Framework queries, the joining operators have no advantage over multiple generators.)

Join and GroupJoin support *equi-joins* only (i.e., the joining condition must use the equality operator). There are two methods: Join and GroupJoin. Join emits a flat result set whereas GroupJoin emits a hierarchical result set.

The query expression syntax for a flat join is:

```
from outer-var in outer-sequence
join inner-var in inner-sequence
  on outer-key-expr equals inner-key-expr
```

For example, given the following collections:

```csharp
var customers = new[]
{   
    new { ID = 1, Name = "Tom" },
    new { ID = 2, Name = "Dick" },
    new { ID = 3, Name = "Harry" }
};
var purchases = new[]
{   
    new { CustomerID = 1, Product = "House" },
    new { CustomerID = 2, Product = "Boat" },
    new { CustomerID = 2, Product = "Car" },
    new { CustomerID = 3, Product = "Holiday" }
};
```

we could perform a join as follows:

```csharp
IEnumerable<string> query =
    from c in customers
    join p in purchases on c.ID equals p.CustomerID
    select c.Name + " bought a " + p.Product;
```

The compiler translates this to:

```
customers.Join (   // outer collection
    purchases,       // inner collection
    c => c.ID,       // outer key selector
    p => p.CustomerID, // inner key selector
    (c, p) => c.Name + " bought a " + p.Product
    );
```

Here’s the result:
Tom bought a House
Dick bought a Boat
Dick bought a Car
Harry bought a Holiday

With local sequences, Join and GroupJoin are more efficient at processing large collections than SelectMany because they first preload the inner sequence into a keyed hashtable-based lookup. With a database query, however, you could achieve the same result equally efficiently as follows:

```csharp
from c in customers
from p in purchases
where c.ID == p.CustomerID
select c.Name + " bought a " + p.Product;
```

### GroupJoin

GroupJoin does the same work as Join, but instead of yielding a flat result, it yields a hierarchical result, grouped by each outer element.

The query expression syntax for GroupJoin is the same as for Join, but is followed by the `into` keyword. Here's a basic example, using the `customers` and `purchases` collections we set up in the previous section:

```csharp
IEnumerable<IEnumerable<Purchase>> query =
    from c in customers
    join p in purchases on c.ID equals p.CustomerID
    into custPurchases
    select custPurchases; // custPurchases is a sequence
```

### NOTE

An `into` clause translates to GroupJoin only when it appears directly after a `join` clause. After a `select` or `group` clause it means `query continuation`. The two uses of the `into` keyword are quite different, although they have one feature in common: they both introduce a new query variable.
The result is a sequence of sequences, which we could enumerate as follows:

```csharp
foreach (IEnumerable<Purchase> purchaseSequence in query)
    foreach (Purchase p in purchaseSequence)
        Console.WriteLine (p.Description);
```

This isn’t very useful, however, because `outerSeq` has no reference to the outer customer. More commonly, you’d reference the outer range variable in the projection:

```csharp
from c in customers
    join p in purchases on c.ID equals p.CustomerID
    into custPurchases
    select new { CustName = c.Name, custPurchases };
```

We could obtain the same result (but less efficiently, for local queries) by projecting into an anonymous type that included a subquery:

```csharp
from c in customers
    select new
    {
        CustName = c.Name,
        custPurchases =
            purchases.Where (p => c.ID == p.CustomerID)
    }
```

**Zip**

Zip is the simplest joining operator. It enumerates two sequences in step (like a zipper), returning a sequence based on applying a function over each element pair. For example:

```csharp
int[] numbers = { 3, 5, 7 };
string[] words = { "three", "five", "seven", "ignored" };
IEnumerable<string> zip =
    numbers.Zip (words, (n, w) => n + "=" + w);
```

produces a sequence with the following elements:

```
3=three
5=five
7=seven
```

Extra elements in either input sequence are ignored. Zip is not supported when querying a database.
**Ordering**

The `orderby` keyword sorts a sequence. You can specify any number of expressions upon which to sort:

```csharp
string[] names = { "Tom","Dick","Harry","Mary","Jay" };

IEnumerable<string> query = from n in names
orderby n.Length, n
select n;
```

This sorts first by length, and then by name, so the result is:

Jay, Tom, Dick, Mary, Harry

The compiler translates the first `orderby` expression to a call to `OrderBy`, and subsequent expressions to a call to `ThenBy`:

```csharp
IEnumerable<string> query = names
.OrderBy (n => n.Length)
.ThenBy (n => n)
```

The `ThenBy` operator refines rather than replaces the previous sorting.

You can include the `descending` keyword after any of the `orderby` expressions:

```csharp
orderby n.Length descending, n
```

This translates to:

```csharp
.OrderByDescending (n => n.Length).ThenBy (n => n)
```

---

**NOTE**

The ordering operators return an extended type of `IEnumerable<T>` called `IOrderedEnumerable<T>`. This interface defines the extra functionality required by the `ThenBy` operator.
Grouping

GroupBy organizes a flat input sequence into sequences of groups. For example, the following groups a sequence of names by their length:

```csharp
string[] names = { "Tom","Dick","Harry","Mary","Jay" };

var query = from name in names
            group name by name.Length;
```

The compiler translates this query into:

```csharp
IEnumerable<IGrouping<int,string>> query =
    names.GroupBy (name => name.Length);
```

Here’s how to enumerate the result:

```csharp
foreach (IGrouping<int,string> grouping in query)
{
    Console.Write ("
Length=" + grouping.Key + ":");
    foreach (string name in grouping)
        Console.Write (" " + name);
}
```

Length=3: Tom Jay
Length=4: Dick Mary
Length=5: Harry

Enumerable.GroupBy works by reading the input elements into a temporary dictionary of lists so that all elements with the same key end up in the same sublist. It then emits a sequence of groupings. A grouping is a sequence with a Key property:

```csharp
public interface IGrouping<TKey,TElement>
    : IEnumerable<TElement>, IEnumerable
{
    // Key applies to the subsequence as a whole
    TKey Key { get; }
}
```

By default, the elements in each grouping are untransformed input elements, unless you specify an elementSelector argument. The following projects each input element to uppercase:

```csharp
from name in names
    group name.ToUpper() by name.Length
```
which translates to this:

```csharp
names.GroupBy (  
    name => name.Length,  
    name => name.ToUpper() )
```

The subcollections are not emitted in order of key. `GroupBy` does no sorting (in fact, it preserves the original ordering). To sort, you must add an `OrderBy` operator (which means first adding an into clause, because `group by` ordinarily ends a query):

```csharp
from name in names  
group name.ToUpper() by name.Length into grouping  
orderby grouping.Key  
select grouping
```

Query continuations are often used in a `group by` query. The next query filters out groups that have exactly two matches in them:

```csharp
from name in names  
group name.ToUpper() by name.Length into grouping  
where grouping.Count() == 2  
select grouping
```

---

**NOTE**

A `where` after a `group by` is equivalent to `HAVING` in SQL. It applies to each subsequence or grouping as a whole, rather than the individual elements.

---

**OfType and Cast**

`OfType` and `Cast` accept a nongeneric `IEnumerable` collection and emit a generic `IEnumerable<T>` sequence that you can subsequently query:

```csharp
var classicList = new System.Collections.ArrayList();  
classicList.AddRange ( new int[] { 3, 4, 5 } );  
IEnumerable<int> sequence1 = classicList.Cast<int>();
```
This is useful because it allows you to query collections written prior to C# 2.0 (when `IEnumerable<T>` was introduced), such as `ControlCollection` in `System.Windows.Forms`.

`Cast` and `OfType` differ in their behavior when encountering an input element that’s of an incompatible type: `Cast` throws an exception whereas `OfType` ignores the incompatible element.

The rules for element compatibility follow those of C#’s `is` operator. Here’s the internal implementation of `Cast`:

```csharp
public static IEnumerable<TSource> Cast<TSource>(IEnumerable source)
{
    foreach (object element in source)
        yield return (TSource)element;
}
```

C# supports the `Cast` operator in query expressions—simply insert the element type immediately after the `from` keyword:

```csharp
from int x in classicList ...
```

This translates to:

```csharp
from x in classicList.Cast<int>() ...
```

## Dynamic Binding

`Dynamic binding` defers binding—the process of resolving types, members, and operations—from compile time to runtime. Dynamic binding was introduced in C# 4.0, and is useful when at compile time you know that a certain function, member, or operation exists, but the compiler does not. This commonly occurs when you are interoperating with dynamic languages (such as IronPython) and COM and in scenarios when you might otherwise use reflection.

A dynamic type is declared with the contextual keyword `dynamic`:

```csharp
dynamic d = GetSomeObject();
d.Quack();
```
A dynamic type tells the compiler to relax. We expect the runtime type of \( d \) to have a \texttt{Quack} method. We just can’t prove it statically. Since \( d \) is dynamic, the compiler defers binding \texttt{Quack} to \( d \) until runtime. To understand what this means requires distinguishing between static binding and dynamic binding.

### Static Binding Versus Dynamic Binding

The canonical binding example is mapping a name to a specific function when compiling an expression. To compile the following expression, the compiler needs to find the implementation of the method named \texttt{Quack}:

\[
d.\text{Quack}();
\]

Let’s suppose the static type of \( d \) is \texttt{Duck}:

\[
\begin{align*}
\text{Duck } d &= \ldots \\
  d.\text{Quack}();
\end{align*}
\]

In the simplest case, the compiler does the binding by looking for a parameterless method named \texttt{Quack} on \texttt{Duck}. Failing that, the compiler extends its search to methods taking optional parameters, methods on base classes of \texttt{Duck}, and extension methods that take \texttt{Duck} as its first parameter. If no match is found, you’ll get a compilation error. Regardless of what method gets bound, the bottom line is that the binding is done by the compiler, and the binding utterly depends on statically knowing the types of the operands (in this case, \( d \)). This makes it static binding.

Now let’s change the static type of \( d \) to \texttt{object}:

\[
\begin{align*}
\text{object } d &= \ldots \\
  d.\text{Quack}();
\end{align*}
\]

Calling \texttt{Quack} gives us a compilation error, because although the value stored in \( d \) can contain a method called \texttt{Quack}, the compiler cannot know it since the only information it has is the type of the variable, which in this case is \texttt{object}. But let’s now change the static type of \( d \) to \texttt{dynamic}:
A dynamic type is like object—it’s equally nondescriptive about a type. The difference is that it lets you use it in ways that aren’t known at compile time. A dynamic object binds at runtime based on its runtime type, not its compile-time type. When the compiler sees a dynamically bound expression (which in general is an expression that contains any value of type dynamic), it merely packages up the expression such that the binding can be done later at runtime.

At runtime, if a dynamic object implements IDynamicMetaObjectProvider, that interface is used to perform the binding. If not, binding occurs in almost the same way as it would have had the compiler known the dynamic object’s runtime type. These two alternatives are called custom binding and language binding.

## Custom Binding

Custom binding occurs when a dynamic object implements IDynamicMetaObjectProvider (IDMOP). Although you can implement IDMOP on types that you write in C#, and this is useful to do, the more common case is that you have acquired an IDMOP object from a dynamic language that is implemented in .NET on the Dynamic Language Runtime (DLR), such as IronPython or IronRuby. Objects from those languages implicitly implement IDMOP as a means to directly control the meanings of operations performed on them. Here’s a simple example:

```csharp
using System;
using System.Dynamic;

public class Test
{
    static void Main()
    {
        dynamic d = new Duck();
        d.Quack(); // Quack was called
        d.Waddle(); // Waddle was called
    }
}
```
public class Duck : DynamicObject
{
    public override bool TryInvokeMember (InvokeMemberBinder binder, object[] args, out object result)
    {
        Console.WriteLine (binder.Name + " was called");
        result = null;
        return true;
    }
}

The Duck class doesn’t actually have a Quack method. Instead, it uses custom binding to intercept and interpret all method calls.

We discuss custom binders in greater detail in Chapter 20 of *C# 5.0 in a Nutshell*.

**Language Binding**

Language binding occurs when a dynamic object does not implement `IDynamicMetaObjectProvider`. Language binding is useful when working around imperfectly designed types or inherent limitations in the .NET type system. A typical problem when using numeric types is that they have no common interface. We have seen that methods can be bound dynamically; the same is true for operators:

```csharp
static dynamic Mean (dynamic x, dynamic y)
{
    return (x + y) / 2;
}
static void Main()
{
    int x = 3, y = 4;
    Console.WriteLine (Mean (x, y));
}
```

The benefit is obvious—you don’t have to duplicate code for each numeric type. However, you lose static type safety, risking runtime exceptions rather than compile-time errors.
NOTE
Dynamic binding circumvents static type safety, but not runtime type safety. Unlike with reflection, you cannot circumvent member accessibility rules with dynamic binding.

By design, language runtime binding behaves as similarly as possible to static binding, had the runtime types of the dynamic objects been known at compile time. In our previous example, the behavior of our program would be identical if we hardcoded `Mean` to work with the `int` type. The most notable exception in parity between static and dynamic binding is for extension methods, which we discuss in the section “Uncallable Functions” on page 174.

NOTE
Dynamic binding also incurs a performance hit. Because of the DLR’s caching mechanisms, however, repeated calls to the same dynamic expression are optimized—allowing you to efficiently call dynamic expressions in a loop. This optimization brings the typical overhead for a simple dynamic expression on today’s hardware down to less than 100 ns.

**RuntimeBinderException**

If a member fails to bind, a **RuntimeBinderException** is thrown. You can think of this like a compile-time error at runtime:

```csharp
dynamic d = 5;
d.Hello(); // throws RuntimeBinderException
```

The exception is thrown because the `int` type has no `Hello` method.
**Runtime Representation of dynamic**

There is a deep equivalence between the dynamic and object types. The runtime treats the following expression as true:

```
typeof (dynamic) == typeof (object)
```

This principle extends to constructed types and array types:

```
typeof (List<dynamic>) == typeof (List<object>)
typeof (dynamic[]) == typeof (object[])
```

Like an object reference, a dynamic reference can point to an object of any type (except pointer types):

```
dynamic x = "hello";
Console.WriteLine (x.GetType().Name);  // String
x = 123;  // No error (despite same variable)
Console.WriteLine (x.GetType().Name);  // Int32
```

Structurally, there is no difference between an object reference and a dynamic reference. A dynamic reference simply enables dynamic operations on the object it points to. You can convert from object to dynamic to perform any dynamic operation you want on an object:

```
object o = new System.Text.StringBuilder();
dynamic d = o;
d.Append ("hello");
Console.WriteLine (o);   // hello
```

**Dynamic Conversions**

The dynamic type has implicit conversions to and from all other types. For a conversion to succeed, the runtime type of the dynamic object must be implicitly convertible to the target static type.

The following example throws a `RuntimeBinderException` because an int is not implicitly convertible to a short:

```
int i = 7;
dynamic d = i;
long l = d;       // OK - implicit conversion works
short j = d;      // throws RuntimeBinderException
```
var Versus dynamic

The var and dynamic types bear a superficial resemblance, but the difference is deep:

    var says, “Let the compiler figure out the type.”
    dynamic says, “Let the runtime figure out the type.”

To illustrate:

    dynamic x = "hello";  // Static type is dynamic
    var y = "hello";      // Static type is string
    int i = x;            // Runtime error
    int j = y;            // Compile-time error

Dynamic Expressions

Fields, properties, methods, events, constructors, indexers, operators, and conversions can all be called dynamically.

Trying to consume the result of a dynamic expression with a void return type is prohibited—just as with a statically typed expression. The difference is that the error occurs at runtime.

Expressions involving dynamic operands are typically themselves dynamic, since the effect of absent type information is cascading:

    dynamic x = 2;
    var y = x * 3;       // Static type of y is dynamic

There are a couple of obvious exceptions to this rule. First, casting a dynamic expression to a static type yields a static expression. Second, constructor invocations always yield static expressions—even when called with dynamic arguments.

In addition, there are a few edge cases where an expression containing a dynamic argument is static, including passing an index to an array and delegate-creation expressions.
Dynamic Member Overload Resolution

The canonical use case for **dynamic** involves a dynamic **receiver**. This means that a dynamic object is the receiver of a dynamic function call:

```csharp
dynamic x = ...;
x.Foo (123);          // x is the receiver
```

However, dynamic binding is not limited to receivers: the method arguments are also eligible for dynamic binding. The effect of calling a function with dynamic arguments is to defer overload resolution from compile-time to runtime:

```csharp
class Program
{
    static void Foo (int x)    { Console.WriteLine ("1"); }
    static void Foo (string x) { Console.WriteLine ("2"); }

    static void Main()
    {
        dynamic x = 5;
        dynamic y = "watermelon";

        Foo (x);    // 1
        Foo (y);    // 2
    }
}
```

Runtime overload resolution is also called **multiple dispatch** and is useful in implementing design patterns such as **visitor**.

If a dynamic receiver is not involved, the compiler can statically perform a basic check to see whether the dynamic call will succeed: it checks that a function with the right name and number of parameters exists. If no candidate is found, you get a compile-time error.

If a function is called with a mixture of dynamic and static arguments, the final choice of method will reflect a mixture of dynamic and static binding decisions:

```csharp
static void X(object x, object y) {Console.Write("oo");}
static void X(object x, string y) {Console.Write("os");}
static void X(string x, object y) {Console.Write("so");}
static void X(string x, string y) {Console.Write("ss");}
```
static void Main()
{
    object o = "hello";
    dynamic d = "goodbye";
    X(o, d);                // os
}

The call to X(o,d) is dynamically bound because one of its arguments, d, is dynamic. But since o is statically known, the binding—even though it occurs dynamically—will make use of that. In this case, overload resolution will pick the second implementation of X due to the static type of o and the runtime type of d. In other words, the compiler is “as static as it can possibly be.”

Uncallable Functions

Some functions cannot be called dynamically. You cannot call:

- Extension methods (via extension method syntax)
- Any member of an interface (via the interface)
- Base members hidden by a subclass

This is because dynamic binding requires two pieces of information: the name of the function to call, and the object upon which to call the function. However, in each of the three uncallable scenarios, an additional type is involved, which is known only at compile time. As of C# 5.0, there is no way to specify these additional types dynamically.

When calling extension methods, that additional type is an extension class, chosen implicitly by virtue of using directives in your source code (which disappear after compilation). When calling members via an interface, the additional type is communicated via an implicit or explicit cast. (With explicit implementation, it’s in fact impossible to call a member without casting to the interface.) A similar situation arises when calling a hidden base member: you must specify an additional type via either a cast or the base keyword—and that additional type is lost at runtime.
Attributes

You’re already familiar with the notion of attributing code elements of a program with modifiers, such as `virtual` or `ref`. These constructs are built into the language. *Attributes* are an extensible mechanism for adding custom information to code elements (assemblies, types, members, return values, and parameters). This extensibility is useful for services that integrate deeply into the type system, without requiring special keywords or constructs in the C# language.

A good scenario for attributes is serialization—the process of converting arbitrary objects to and from a particular format. In this scenario, an attribute on a field can specify the translation between C#’s representation of the field and the format’s representation of the field.

Attribute Classes

An attribute is defined by a class that inherits (directly or indirectly) from the abstract class `System.Attribute`. To attach an attribute to a code element, specify the attribute’s type name in square brackets, before the code element. For example, the following attaches the `ObsoleteAttribute` to the `Foo` class:

```csharp
[ObsoleteAttribute]
public class Foo {...}
```

This attribute is recognized by the compiler and will cause compiler warnings if a type or member marked obsolete is referenced. By convention, all attribute types end with the word `Attribute`. C# recognizes this and allows you to omit the suffix when attaching an attribute:

```csharp
[Obsolete]
public class Foo {...}
```

`ObsoleteAttribute` is a type declared in the `System` namespace as follows (simplified for brevity):

```csharp
public sealed class ObsoleteAttribute : Attribute {...}
```
Named and Positional Attribute Parameters

Attributes may have parameters. In the following example, we apply `XmlElementAttribute` to a class. This attribute tells `XmlSerializer` how an object is represented in XML and accepts several attribute parameters. The following attribute maps the `CustomerEntity` class to an XML element named `Customer`, belonging to the `http://oreilly.com` namespace:

```csharp
[XmlElement("Customer", Namespace="http://oreilly.com")]
public class CustomerEntity { ... }
```

Attribute parameters fall into one of two categories: positional or named. In the preceding example, the first argument is a positional parameter; the second is a named parameter. Positional parameters correspond to parameters of the attribute type’s public constructors. Named parameters correspond to public fields or public properties on the attribute type.

When specifying an attribute, you must include positional parameters that correspond to one of the attribute’s constructors. Named parameters are optional.

Attribute Targets

Implicitly, the target of an attribute is the code element it immediately precedes, which is typically a type or type member. You can also attach attributes, however, to an assembly. This requires that you explicitly specify the attribute’s target.

Here is an example of using the `CLSCompliant` attribute to specify Common Language Specification (CLS) compliance for an entire assembly:

```csharp
[assembly:CLSCompliant(true)]
```

Specifying Multiple Attributes

Multiple attributes can be specified for a single code element. Each attribute can be listed either within the same pair of
square brackets (separated by a comma) or in separate pairs of square brackets (or a combination of the two). The following two examples are semantically identical:

```csharp
[Serializable, Obsolete, CLSCompliant(false)]
public class Bar {...}

[Serializable] [Obsolete] [CLSCompliant(false)]
public class Bar {...}
```

### Writing Custom Attributes

You can define your own attributes by subclassing `System.Attribute`. For example, we could use the following custom attribute for flagging a method for unit testing:

```csharp
[AttributeUsage (AttributeTargets.Method)]
public sealed class TestAttribute : Attribute
{
    public int     Repetitions;
    public string  FailureMessage;

    public TestAttribute () : this (1) { }
    public TestAttribute (int repetitions)
    {
        Repetitions = repetitions;
    }
}
```

Here’s how we could apply the attribute:

```csharp
class Foo
{
    [Test]
    public void Method1() { ... }

    [Test(20)]
    public void Method2() { ... }

    [Test(20, FailureMessage="Debugging Time!")]
    public void Method3() { ... }
}
```

`AttributeUsage` is itself an attribute that indicates the construct (or combination of constructs) that the custom attribute can be applied to. The `AttributeTargets` enum includes such
members as `Class`, `Method`, `Parameter`, and `Constructor` (as well as `All`, which combines all targets).

## Retrieving Attributes at Runtime

There are two standard ways to retrieve attributes at runtime:

- Call `GetCustomAttributes` on any `Type` or `MemberInfo` object.
- Call `Attribute.GetCustomAttribute` or `Attribute.GetCustomAttributes`.

These latter two methods are overloaded to accept any reflection object that corresponds to a valid attribute target (`Type`, `Assembly`, `Module`, `MemberInfo`, or `ParameterInfo`).

Here’s how we can enumerate each method in the preceding `Foo` class that has a `TestAttribute`:

```csharp
foreach (MethodInfo mi in typeof (Foo).GetMethods())
{
    TestAttribute att = (TestAttribute) Attribute.GetCustomAttribute(mi, typeof (TestAttribute));

    if (att != null)
        Console.WriteLine ("{0} will be tested; reps={1}; msg={2}", mi.Name, att.Repetitions, att.FailureMessage);
}
```

Here’s the output:

```
Method1 will be tested; reps=1; msg=
Method2 will be tested; reps=20; msg=
Method3 will be tested; reps=20; msg=Debugging Time!
```

## Caller Info Attributes (C# 5.0)

Starting with C# 5.0, you can tag optional parameters with one of three `caller info attributes`, which instruct the compiler to feed information obtained from the caller’s source code into the parameter’s default value:
• [CallerMemberName] applies the caller’s member name.
• [CallerFilePath] applies the path to the caller’s source code file.
• [CallerLineNumber] applies the line number in the caller’s source code file.

The Foo method in the following program demonstrates all three:

```csharp
using System;
using System.Runtime.CompilerServices;

class Program
{
    static void Main()
    {
        Foo();
    }

    static void Foo (string memberName = null, string filePath = null, int lineNumber = 0)
    {
        Console.WriteLine (memberName);
        Console.WriteLine (filePath);
        Console.WriteLine (lineNumber);
    }
}
```

Assuming our program resides in `c:\source\test\Program.cs`, the output would be:

```
Main
c:\source\test\Program.cs
8
```

As with standard optional parameters, the substitution is done at the calling site. Hence, our `Main` method is syntactic sugar for this:

```csharp
static void Main()
{
    Foo ("Main", @"c:\source\test\Program.cs", 8);
}
```
Caller info attributes are useful for writing logging functions, and for implementing change notification patterns. For instance, a method such as the following can be called from inside a property’s set accessor—without having to specify the property’s name:

```csharp
void RaisePropertyChanged (  
    [CallerMemberName] string propertyName = null)  
{  
    ...
}
```

**Asynchronous Functions (C# 5.0)**

C# 5.0 introduces the `await` and `async` keywords to support asynchronous programming, a style of programming where long-running functions do most or all of their work after returning to the caller. This is in contrast to normal synchronous programming, where long-running functions block the caller until the operation is complete. Asynchronous programming implies concurrency, since the long-running operation continues in parallel to the caller. The implementer of an asynchronous function initiates this concurrency either through multithreading (for compute-bound operations) or via a callback mechanism (for I/O-bound operations).

---

**NOTE**

Multithreading, concurrency, and asynchronous programming are large topics. We dedicate two chapters to them in *C# 5.0 in a Nutshell*, and discuss them online at [http://albahari.com/thrading](http://albahari.com/thrading).

---

For instance, consider the following synchronous method, which is long-running and compute-bound:

```csharp
int ComplexCalculation()  
{  
    double x = 2;  
    for (int i = 1; i < 100000000; i++)
```
x += Math.Sqrt (x) / i;
return (int)x;
}

This method blocks the caller for a few seconds while it runs. The result of the calculation is then returned to the caller:

```csharp
int result = ComplexCalculation();
// Sometime later:
Console.WriteLine (result);  // 116
```

The CLR defines a class called `Task<TResult>` (in `System.Threading.Tasks`) to encapsulate the concept of an operation that completes in the future. You can generate a `Task<TResult>` for a compute-bound operation by calling `Task.Run`, which tells the CLR to run the specified delegate on a separate thread that executes in parallel to the caller:

```csharp
Task<int> ComplexCalculationAsync()
{
    return Task.Run (() => ComplexCalculation());
}
```

This method is *asynchronous* because it returns immediately to the caller while it executes concurrently. However, we need some mechanism to allow the caller to specify what should happen when the operation finishes and the result becomes available. `Task<TResult>` solves this by exposing a `GetAwaiter` method which lets the caller attach a continuation:

```csharp
Task<int> task = ComplexCalculationAsync();
var awaiter = task.GetAwaiter();
awaiter.OnCompleted (() =>        // Continuation
{
    int result = awaiter.GetResult();
    Console.WriteLine (result);       // 116
});
```

This says to the operation, “When you finish, execute the specified delegate.” Our continuation first calls `GetResult` which returns the result of the calculation. (Or, if the task *faulted* [threw an exception], calling `GetResult` rethrows that exception.) Our continuation then writes out the result via `Console.WriteLine`.
The await and async Keywords

The `await` keyword simplifies the attaching of continuations. Starting with a basic scenario, the compiler expands:

```csharp
var result = await expression;
statement(s);
```

into something functionally similar to:

```csharp
var awaiter = expression.GetAwaiter();
awaiter.OnCompleted(() =>
{
    var result = awaiter.GetResult();
    statement(s);
});
```

NOTE

The compiler also emits code to optimize the scenario of the operation completing synchronously (immediately). The most common reason for an asynchronous operation completing immediately is if it implements an internal caching mechanism, and the result is already cached.

Hence, we can call the `ComplexCalculationAsync` method we defined previously, like this:

```csharp
int result = await ComplexCalculationAsync();
Console.WriteLine(result);
```

In order to compile, we need to add the `async` modifier to the containing method:

```csharp
async void Test()
{
    int result = await ComplexCalculationAsync();
    Console.WriteLine(result);
}
```

The `async` modifier tells the compiler to treat `await` as a keyword rather than an identifier should an ambiguity arise within that method (this ensures that code written prior to C# 5.0
that might use `await` as an identifier will still compile without error). The `async` modifier can be applied only to methods (and lambda expressions) that return `void` or (as we’ll see later) a `Task` or `Task<TResult>`.

**NOTE**

The `async` modifier is similar to the `unsafe` modifier in that it has no effect on a method’s signature or public metadata; it affects only what happens inside the method.

Methods with the `async` modifier are called *asynchronous functions*, because they themselves are typically asynchronous. To see why, let’s look at how execution proceeds through an asynchronous function.

Upon encountering an `await` expression, execution (normally) returns to the caller—rather like with `yield return` in an iterator. But before returning, the runtime attaches a continuation to the awaited task, ensuring that when the task completes, execution jumps back into the method and continues where it left off. If the task faults, its exception is rethrown (by virtue of calling `GetResult`); otherwise, its return value is assigned to the `await` expression.

**NOTE**

The CLR’s implementation of a task awaiter’s `OnCompleted` method ensures that by default, continuations are posted through the current *synchronization context*, if one is present. In practice, this means that in rich-client UI scenarios (WPF, Metro, Silverlight, and Windows Forms), if you `await` on a UI thread, your code will continue on that same thread. This simplifies thread safety.
The expression upon which you `await` is typically a task; however, any object with a `GetAwaiter` method that returns an `awaitable object`—implementing `INotifyCompletion.OnCompleted` and with an appropriately typed `GetResult` method (and a `bool IsCompleted` property which tests for synchronous completion)—will satisfy the compiler.

Notice that our `await` expression evaluates to an `int` type; this is because the expression that we awaited was a `Task<int>` (whose `GetAwaiter().GetResult()` method returns an `int`).

Awaiting a nongeneric task is legal and generates a `void` expression:

```csharp
await Task.Delay (5000);
Console.WriteLine ("Five seconds passed!");
```

`Task.Delay` is a static method that returns a `Task` that completes in the specified number of milliseconds. The `synchronous` equivalent of `Task.Delay` is `Thread.Sleep`.

`Task` is the nongeneric base class of `Task<TResult>` and is functionally equivalent to `Task<TResult>` except that it has no result.

### Capturing Local State

The real power of `await` expressions is that they can appear almost anywhere in code. Specifically, an `await` expression can appear in place of any expression (within an asynchronous function) except for inside a `catch` or `finally` block, a `lock` expression, an `unsafe` context, or an executable’s entry point (main method).

In the following example, we `await` inside a loop:

```csharp
async void Test()
{
    for (int i = 0; i < 10; i++)
    {
        int result = await ComplexCalculationAsync();
        Console.WriteLine (result);
    }
}
```
Upon first executing `ComplexCalculationAsync`, execution returns to the caller by virtue of the `await` expression. When the method completes (or faults), execution resumes where it left off, with the values of local variables and loop counters preserved. The compiler achieves this by translating such code into a state machine, like it does with iterators.

Without the `await` keyword, the manual use of continuations means that you must write something equivalent to a state machine. This is traditionally what makes asynchronous programming difficult.

**Writing Asynchronous Functions**

With any asynchronous function, you can replace the `void` return type with a `Task` to make the method itself *usefully* asynchronous (and `awaitable`). No further changes are required:

```csharp
async Task PrintAnswerToLife()
{
    await Task.Delay (5000);
    int answer = 21 * 2;
    Console.WriteLine (answer);
}
```

Notice that we don’t explicitly return a task in the method body. The compiler manufactures the task, which it signals upon completion of the method (or upon an unhandled exception). This makes it easy to create asynchronous call chains:

```csharp
async Task Go()
{
    await PrintAnswerToLife();
    Console.WriteLine ("Done");
}
```

(And because `Go` returns a `Task`, `Go` itself is awaitable.) The compiler expands asynchronous functions that return tasks into code that (indirectly) leverages `TaskCompletionSource` to create a task that it then signals or faults.
NOTE

TaskCompletionSource is a CLR type that lets you create tasks that you manually control, signaling them as complete with a result (or as faulted with an exception). Unlike Task.Run, TaskCompletionSource doesn’t tie up a thread for the duration of the operation. It’s also used for writing I/O-bound task-returning methods (such as Task.Delay).

The aim is to ensure that when a task-returning asynchronous method finishes, execution can jump back to whoever awaited it, via a continuation.

Returning Task<TResult>

You can return a Task<TResult> if the method body returns TResult:

```csharp
async Task<int> GetAnswerToLife()
{
    await Task.Delay (5000);
    int answer = 21 * 2;
    // answer is int so our method returns Task<int>
    return answer;
}
```

We can demonstrate GetAnswerToLife by calling it from PrintAnswerToLife (which is, in turn, called from Go):

```csharp
async Task Go()
{
    await PrintAnswerToLife();
    Console.WriteLine ("Done");
}
async Task PrintAnswerToLife()
{
    int answer = await GetAnswerToLife();
    Console.WriteLine (answer);
}
async Task<int> GetAnswerToLife()
{
    await Task.Delay (5000);
    int answer = 21 * 2;
    return answer;
}
```
Asynchronous functions make asynchronous programming similar to synchronous programming. Here’s the synchronous equivalent of our call graph, for which calling Go() gives the same result after blocking for five seconds:

```csharp
void Go()
{
    PrintAnswerToLife();
    Console.WriteLine("Done");
}

void PrintAnswerToLife()
{
    int answer = GetAnswerToLife();
    Console.WriteLine(answer);
}

int GetAnswerToLife()
{
    Thread.Sleep(5000);
    int answer = 21 * 2;
    return answer;
}
```

This also illustrates the basic principle of how to design with asynchronous functions in C#, which is to write your methods synchronously, and then replace synchronous method calls with asynchronous method calls, and await them.

**Parallelism**

We’ve just demonstrated the most common pattern, which is to await task-returning functions right after calling them. This results in sequential program flow that’s logically similar to the synchronous equivalent.

Calling an asynchronous method without awaiting it allows the code that follows to execute in parallel. For example, the following executes PrintAnswerToLife twice, concurrently:

```csharp
var task1 = PrintAnswerToLife();
var task2 = PrintAnswerToLife();
await task1; await task2;
```
By awaiting both operations afterward, we “end” the parallelism at that point (and rethrow any exceptions from those tasks). The `Task` class provides a static method called `WhenAll` to achieve the same result slightly more efficiently. `WhenAll` returns a task that completes when all of the tasks that you pass to it complete:

```csharp
await Task.WhenAll (PrintAnswerToLife(), PrintAnswerToLife());
```

`WhenAll` is a called task combinator. (The `Task` class also provides a task combinator called `WhenAny`, which completes when any of the tasks provided to it complete.) We cover the task combinators in detail in *C# 5.0 in a Nutshell*.

### Asynchronous Lambda Expressions

Just as ordinary named methods can be asynchronous:

```csharp
async Task NamedMethod()
{
    await Task.Delay (1000);
    Console.WriteLine ("Foo");
}
```

so can unnamed methods (lambda expressions and anonymous methods), if preceded by the `async` keyword:

```csharp
Func<Task> unnamed = async () =>
{
    await Task.Delay (1000);
    Console.WriteLine ("Foo");
};
```

We can call and await these in the same way:

```csharp
await NamedMethod();
await unnamed();
```

Asynchronous lambda expressions can be used when attaching event handlers:

```csharp
myButton.Click += async (sender, args) =>
{
    await Task.Delay (1000);
}
```
myButton.Content = "Done";
};

This is more succinct than the following, which has the same effect:

myButton.Click += ButtonHandler;
...
async void ButtonHandler (object sender, EventArgs args)
{
    await Task.Delay (1000);
    myButton.Content = "Done";
};

Asynchronous lambda expressions can also return Task<TResult>:

Func<Task<int>> unnamed = async () =>
{
    await Task.Delay (1000);
    return 123;
};
int answer = await unnamed();

### Unsafe Code and Pointers

C# supports direct memory manipulation via pointers within blocks of code marked unsafe and compiled with the /unsafe compiler option. Pointer types are primarily useful for interoperability with C APIs, but may also be used for accessing memory outside the managed heap or for performance-critical hotspots.

### Pointer Basics

For every value type or pointer type $V$, there is a corresponding pointer type $V^*$. A pointer instance holds the address of a variable. Pointer types can be (unsafely) cast to any other pointer type. The main pointer operators are:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp;</td>
<td>The address-of operator returns a pointer to the address of a variable.</td>
</tr>
<tr>
<td>Operator</td>
<td>Meaning</td>
</tr>
<tr>
<td>----------</td>
<td>---------</td>
</tr>
<tr>
<td>*</td>
<td>The dereference operator returns the variable at the address of a pointer.</td>
</tr>
<tr>
<td>-&gt;</td>
<td>The pointer-to-member operator is a syntactic shortcut, in which x-&gt;y is equivalent to (*x).y.</td>
</tr>
</tbody>
</table>

**Unsafe Code**

By marking a type, type member, or statement block with the `unsafe` keyword, you’re permitted to use pointer types and perform C++-style pointer operations on memory within that scope. Here is an example of using pointers to quickly process a bitmap:

```csharp
unsafe void BlueFilter (int[,] bitmap)
{
    int length = bitmap.Length;
    fixed (int* b = bitmap)
    {
        int* p = b;
        for (int i = 0; i < length; i++)
            *p++ &= 0xFF;
    }
}
```

Unsafe code can run faster than a corresponding safe implementation. In this case, the code would have required a nested loop with array indexing and bounds checking. An unsafe C# method may also be faster than calling an external C function, since there is no overhead associated with leaving the managed execution environment.

**The fixed Statement**

The `fixed` statement is required to pin a managed object, such as the bitmap in the previous example. During the execution of a program, many objects are allocated and deallocated from the heap. In order to avoid unnecessary waste or fragmentation of memory, the garbage collector moves objects around. Pointing to an object is futile if its address could change while referencing it, so the `fixed` statement tells the garbage collector
to “pin” the object and not move it around. This may have an impact on the efficiency of
the runtime, so fixed blocks should be used only briefly, and heap allocation should be avoided
within the fixed block.

Within a fixed statement, you can get a pointer to a value type, an array of value types, or a string.
In the case of arrays and strings, the pointer will actually point to the first element, which is a value type.

Value types declared inline within reference types require the reference type to be pinned, as follows:

class Test
{
    int x;
    unsafe static void Main()
    {
        Test test = new Test();
        fixed (int* p = &test.x) // Pins test
        {
            *p = 9;
        }
        System.Console.WriteLine (test.x);
    }
}

The Pointer-to-Member Operator

In addition to the & and * operators, C# also provides the C++-style -> operator, which can be used on structs:

struct Test
{
    int x;
    unsafe static void Main()
    {
        Test test = new Test();
        Test* p = &test;
        p->x = 9;
        System.Console.WriteLine (test.x);
    }
}
Arrays

The stackalloc keyword

Memory can be allocated in a block on the stack explicitly using the `stackalloc` keyword. Since it is allocated on the stack, its lifetime is limited to the execution of the method, just as with any other local variable. The block may use the `[ ]` operator to index into memory:

```csharp
int* a = stackalloc int [10];
for (int i = 0; i < 10; ++i)
    Console.WriteLine (a[i]);   // Print raw memory
```

Fixed-size buffers

Memory can be allocated in a block within a struct using the `fixed` keyword:

```csharp
unsafe struct UnsafeUnicodeString
{
    public short Length;
    public fixed byte Buffer[30];
}

unsafe class UnsafeClass
{
    UnsafeUnicodeString uus;

    public UnsafeClass (string s)
    {
        uus.Length = (short)s.Length;
        fixed (byte* p = uus.Buffer)
            for (int i = 0; i < s.Length; i++)
                p[i] = (byte) s[i];
    }
}
```

The `fixed` keyword is also used in this example to pin the object on the heap that contains the buffer (which will be the instance of `UnsafeClass`).
void*

A void pointer (void*) makes no assumptions about the type of the underlying data and is useful for functions that deal with raw memory. An implicit conversion exists from any pointer type to void*. A void* cannot be dereferenced, and arithmetic operations cannot be performed on void pointers. For example:

```csharp
unsafe static void Main()
{
    short[] a = {1,1,2,3,5,8,13,21,34,55};
    fixed (short* p = a)
    {
        // sizeof returns size of value-type in bytes
        Zap (p, a.Length * sizeof (short));
    }
    foreach (short x in a)
    {
        System.Console.WriteLine (x); // Prints all zeros
    }
}

unsafe static void Zap (void* memory, int byteCount)
{
    byte* b = (byte*) memory;
    for (int i = 0; i < byteCount; i++)
    {
        *b++ = 0;
    }
}
```

Preprocessor Directives

Preprocessor directives supply the compiler with additional information about regions of code. The most common preprocessor directives are the conditional directives, which provide a way to include or exclude regions of code from compilation. For example:

```csharp
#define DEBUG
class MyClass
{
    int x;
    void Foo()
    {
        # if DEBUG
```
In this class, the statement in Foo is compiled as conditionally dependent upon the presence of the DEBUG symbol. If we remove the DEBUG symbol, the statement is not compiled. Preprocessor symbols can be defined within a source file (as we have done), and they can be passed to the compiler with the / define:symbol command-line option.

With the #if and #elif directives, you can use the ||, &&, and ! operators to perform or, and, and not operations on multiple symbols. The following directive instructs the compiler to include the code that follows if the TESTMODE symbol is defined and the DEBUG symbol is not defined:

```
#if TESTMODE && !DEBUG
... 
#endif
```

Bear in mind, however, that you’re not building an ordinary C# expression, and the symbols upon which you operate have absolutely no connection to variables—static or otherwise.

The #error and #warning symbols prevent accidental misuse of conditional directives by making the compiler generate a warning or error given an undesirable set of compilation symbols.

Here is a complete list of preprocessor directives:

<table>
<thead>
<tr>
<th>Preprocessor directive</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>#define symbol</td>
<td>Defines symbol.</td>
</tr>
<tr>
<td>#undef symbol</td>
<td>Undefines symbol.</td>
</tr>
<tr>
<td>#if symbol [operator symbol2]...</td>
<td>Conditional compilation (operators are ==, !=, &amp;&amp;, and</td>
</tr>
<tr>
<td>#else</td>
<td>Executes code to subsequent #endif.</td>
</tr>
<tr>
<td>#elif symbol [operator symbol2]</td>
<td>Combines #else branch and #if test.</td>
</tr>
</tbody>
</table>
Preprocessor directive | Action
--- | ---
#define | Ends conditional directives.
#warning text | text of the warning to appear in compiler output.
#error text | text of the error to appear in compiler output.
#line [number | hidden] | number specifies the line in source code; file is the filename to appear in computer output; hidden instructs debuggers to skip over code from this point until the next #line directive.
#region name | Marks the beginning of an outline.
#endregion | Ends an outline region.
#pragma warning | See the next section.

Pragma Warning

The compiler generates a warning when it spots something in your code that seems unintentional. Unlike errors, warnings don’t ordinarily prevent your application from compiling.

Compiler warnings can be extremely valuable in spotting bugs. Their usefulness, however, is undermined when you get false warnings. In a large application, maintaining a good signal-to-noise ratio is essential if the “real” warnings are to get noticed.

To this effect, the compiler allows you to selectively suppress warnings with the #pragma warning directive. In this example, we instruct the compiler not to warn us about the field Message not being used:

```csharp
public class Foo
{
    static void Main() {} } 
```
Omitting the number in the `#pragma warning` directive disables or restores all warning codes.

If you are thorough in applying this directive, you can compile with the `/warnaserror` switch—this tells the compiler to treat any residual warnings as errors.

**XML Documentation**

A *documentation comment* is a piece of embedded XML that documents a type or member. A documentation comment comes immediately before a type or member declaration, and starts with three slashes:

```csharp
/// <summary>Cancels a running query.</summary>
public void Cancel() { ... }
```

Multiline comments can be done either like this:

```csharp
/// <summary>
/// Cancels a running query
/// </summary>
public void Cancel() { ... }
```

or like this (notice the extra star at the start):

```csharp
/**
 * <summary>Cancels a running query. </summary>
 */
public void Cancel() { ... }
```

If you compile with the `/doc` directive, the compiler extracts and collates documentation comments into a single XML file. This has two main uses:

- If placed in the same folder as the compiled assembly, Visual Studio automatically reads the XML file and uses the information to provide IntelliSense member listings to consumers of the assembly of the same name.
• Third-party tools (such as Sandcastle and NDoc) can transform an XML file into an HTML help file.

Standard XML Documentation Tags

Here are the standard XML tags that Visual Studio and documentation generators recognize:

<summary>

<summary>...</summary>

Indicates the tool tip that IntelliSense should display for the type or member. Typically a single phrase or sentence.

<remarks>

<remarks>...</remarks>

Additional text that describes the type or member. Documentation generators pick this up and merge it into the bulk of a type or member’s description.

<param>

<param name="name">...</param>

Explains a parameter on a method.

<returns>

<returns>...</returns>

Explains the return value for a method.

<exception>

<exception cref="type">...</exception>

Lists an exception that a method may throw (cref refers to the exception type).

<permission>

<permission cref="type">...</permission>

Indicates an IPermission type required by the documented type or member.
Denotes an example (used by documentation generators). This usually contains both description text and source code (source code is typically within a `<c>` or `<code>` tag).

`<c>`

`<c>...</c>`

Indicates an inline code snippet. This tag is usually used inside an `<example>` block.

`<code>`

`<code>...</code>`

Indicates a multiline code sample. This tag is usually used inside an `<example>` block.

`<see>`

`<see cref="member">...</see>`

Inserts an inline cross-reference to another type or member. HTML documentation generators typically convert this to a hyperlink. The compiler emits a warning if the type or member name is invalid.

`<seealso>`

`<seealso cref="member">...</seealso>`

Cross-references another type or member. Documentation generators typically write this into a separate “See Also” section at the bottom of the page.

`<paramref>`

`<paramref name="name"/>`

References a parameter from within a `<summary>` or `<remarks>` tag.

`<list>`

`<list type=[ bullet | number | table ]>
  <listheader>
    <term>...</term>
  </listheader>`

198  |  C# 5.0 Pocket Reference
Instructs documentation generators to emit a bulleted, numbered, or table-style list.

Instructs documentation generators to format the contents into a separate paragraph.

Merges an external XML file that contains documentation. The path attribute denotes an XPath query to a specific element in that file.
Joseph Albahari is author of *C# 4.0 in a Nutshell*, *LINQ Pocket Reference*, and *C# 4.0 Pocket Reference*. He has been developing large-scale enterprise applications on .NET and other platforms for more than 15 years, and is author of LINQPad, the popular utility for querying databases in LINQ. Joseph is currently a freelance consultant. He can be found at [http://albahari.net/](http://albahari.net/).

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Symbols

& (ampersand)
   & address-of operator, 189
   & bitwise and operator, 24
   & conditional and operator,
      28, 194
   &= and self by operator, 46

* (asterisk)
   * dereference (value at)
      operator, 189
   * multiplication operator, 6,
      23
   *= multiply self by operator,
      46

@ (at sign)
   @ preceding identifiers, 9
   @ preceding verbatim string
      literals, 30
\ (backslash)
   \ escape sequence for, 29
   \ preceding escape sequences,
      29

{ } (braces)
   { } enclosing statement
      blocks, 10, 51

^ (caret)
   ^ bitwise xor operator, 24
   ^= xor self by operator, 46
   = (equal sign)
      = assignment operator, 10,
         44
   == equal to operator, 25, 27
   => lambda operator, 114
   ! (exclamation mark)
      ! not operator, 28, 194
      != not equal to operator, 27
   / (forward slash)
      / division operator, 23
      // preceding comments, 4
      /= divide self by operator, 46
   # (hash mark)
      # preceding preprocessor
         directives, 193
   < (left angle bracket)
      < less than operator, 27
      << shift left operator, 24
      <<= shift self left by operator,
         46
      <= less than or equal to
         operator, 27
   - (minus sign)
      - negative value of operator,
         46

We’d like to hear your suggestions for improving our indexes. Send email to
index@oreilly.com.
- removing delegate instances, 103
- subtraction operator, 23
-- decrement operator, 23
-= event accessor
  implementation, 112
-= removing delegate
  instances, 103
-= subtract from self operator, 46
-> pointer-to-member
  operator, 189, 191
( ) (parentheses)
  () cast operator, 15, 72, 80,
  133
  () method call or declaration,
  10
% (percent sign)
  % remainder operator, 23
. (period)
  . member access operator, 10,
  57
+ (plus sign)
  + addition operator, 23
  + combining delegate
    instances, 103
  + positive value of operator, 46
  + string concatenation
    operator, 31
++ increment operator, 23
+= add to self operator, 46
+= combining delegate
  instances, 103
+= event accessor
  implementation, 112
? (question mark)
  ? in nullable types, 132
  ?: ternary conditional
    operator, 28
  ?? null coalescing operator,
  135
“ (quotes, double)
  escape sequence for, 29
  specifying string literals, 30
‘ (quotes, single)
  escape sequence for, 29
> (right angle bracket)
  > greater than operator, 27
  >= greater than or equal to
    operator, 27
  >> shift right operator, 24
  >>= shift self right by
    operator, 46
; (semicolon)
  ; terminating statements, 10
[ ] (square brackets)
  [] array declaration or index,
  32
  [] enclosing attribute names,
  175
  [] indexer declaration, 67
~ (tilde)
  ~ bitwise complement
    operator, 24
  ~ prefixing finalizers, 69
| (vertical bar)
  | bitwise or operator, 24
  |= or self by operator, 46
  || conditional or operator, 28,
  194

A
abstract classes, 75
access levels of accessors, 66
access modifiers, 84–86
accessibility capping, 85
accessors, 65, 66, 112
Action delegate, 105
add to self operator (+=), 46
addition operator (+), 23
address-of operator (&), 189
Aggregate operator, LINQ, 151
aggregating elements, LINQ, 145,
  149, 151
alert, escape sequence for, 29
aliasing, 60
All operator, LINQ, 146, 151
and operator, bitwise (&), 24
and operator, conditional (&&),
  28, 194
and self by operator (&=), 46
anonymous methods, 117–118
anonymous types, 141
Any operator, LINQ, 146, 151
ArgumentException class, 125
ArgumentNullException class, 125
ArgumentOutOfRangeException class, 125
arguments, 5, 37, 38–43
named arguments, 42
type arguments, 93
arithmetic operators, 23
Array class, 33
arrays, 32–36
allocating to stack, 192
allocating within a struct, 192
automatic initialization of, 37
copying, 33
initializing, 33, 35
iterating through, 32
jagged, 34
multidimensional, 34
rectangular, 34
searching, 33
sorting, 33
as operator, 73
AsEnumerable operator, LINQ, 152
AsQueryable operator, LINQ, 152
assemblies, 7, 85
assignment operator (=), 10, 44
assignment operators, 10
assignment expressions, 44
compound, 45, 136
reference types, 18
value types, 16
assignment, definite, 37
associativity of operators, 45
async keyword, 180, 182–184
asynchronous functions, 180–189
lambda expressions, 188–189
local state, capturing, 184–185
parallelism with, 187–188
returning a task, 186
writing, 185–187
attributes, 175–180
attribute classes, 175
attribute parameters, 176
caller info attributes, 178–180
custom attributes, 177
multiple, specifying, 176
retrieving at runtime, 178
targets of, 176
automatic properties, 66
Average operator, LINQ, 145, 151
await keyword, 180, 182–184
B
backspace, escape sequence for, 29
base class constructor, 76
base class generic constraint, 97
base classes, 70
inheritance from, 72, 75
object type as, 79
upcasting to, 72
base keyword, 76, 77
binary operators, 44
BinarySearch method, 33
binding
dynamic binding, 166–174
static binding, 167–168
BitArray class, 27
bitwise operators, 24
bool type, 12, 27, 38, 135
boxing, 80, 133
break statement, 52, 55
broadcasters, 108
built-in types (see predefined types)
byte type, 20, 25

C
<c> XML tag, 198
callbacks (see delegates)
caller info attributes, 178–180
CallerFilePath attribute, 178
CallerLineNumber attribute, 178
CallerMemberName attribute, 178
captured variables, 115
carriage return, escape sequence for, 29
case clause, switch statement, 52
cast operator ((())), 15, 72, 80, 133
Cast operator, LINQ, 152, 165–166
casting, 15, 72–74, 80
(see also boxing; conversions)
  enums, 90
  implicit, to interface, 87
to object type, 79
catch block, 119, 120–121
chaining extension methods, 140
chaining query operators, LINQ, 152–153
char literals, 29
char type, 29, 38
checked operator, 24
class generic constraint, 97
class keyword, 60
classes, 6, 60–71
  abstract classes, 75
  base classes (see base classes)
  declaring, 60
  identifiers for, 8
  sealing, 76
  static classes, 14, 69
  subclasses (see subclasses)
closed types, 94
closure, 115
<code> XML tag, 198
combinable enums, 91
comments, 4, 11, 196–199
CompareTo method, 31
comparison operators, 27, 31, 137
compilation, 7
complement operator, bitwise (~), 24
Concat operator, LINQ, 146, 150
concatenating strings, 31
concurrency (see asynchronous functions)
conditional operators, 28
constants, 11, 37, 68
  as expressions, 43
  declaring, 49
  group of (see enum type)
  constraints, 97
constructors, 14, 62–63
  field initialization order with, 78
  implicit parameterless constructors, 62
  nonpublic, 63
  of subclasses, 77
  overloading, 62
  parameterless, 78
  static constructors, 68
  struct, 84
Contains method, 31
Contains operator, LINQ, 146, 151
contextual keywords, 10
continue statement, 55
contravariance, 101, 106
conversions, 15
  boxing, 80
  char type, 30
  custom conversions, 138
dynamic types, 171
  enums, 90
  explicit, 15, 22, 138
  implicit, 15, 22, 138
  LINQ, 147, 149, 152, 165
  nullable types, 133, 135
  numeric, 22
  reference conversions, 72
Copy method, 33
Count operator, LINQ, 145, 151
covariance, 99–101, 106
CreateInstance method, 33
cs files (source code), 7
csc.exe file (compiler), 7
custom attributes, 177
custom binding, 168–169
custom types, 12

data members, 13, 14
decimal type, 20, 26
declaration statements, 49
decrement operator (--), 23
default keyword, 38, 96
DefaultIfEmpty operator, LINQ, 151
defered execution, LINQ, 147–148
#define directive, 194
definite assignment, 37
delegate keyword, 118
delegates, 101–108
  Action delegate, 105
  compatibility of types, 106–108
  Func delegate, 105
  generic delegate types, 104, 107
  instance methods assigned to, 104
  multicast delegates, 103
  parameter variance, 106
  plug-in methods using, 102
  return type variance, 106
dereference (value at) operator (*), 189
derived classes (see subclasses)
destructors (see finalizers)
directives, preprocessor, 193–196
Dispose method, 122
Distinct operator, LINQ, 149
divide self by operator (/=), 46
DivideByZeroException, 119
division, 23, 25, 119
division operator (/), 23
dll files (library), 7
do-while loops, 53
/doc directive, 196
documentation comments, 196–199
double type, 20, 25, 26
downcasting, 72, 73
dynamic binding, 166–174
compared to object types, 171
compared to static binding, 167–168
compared to var types, 172
conversions, 171
custom binding, 168–169
dynamic expressions, 172
language binding, 169–170
overload resolution, 173–174
RuntimeBinderException from, 170
uncallable functions, 174

decisional integral types, 25
element operators, LINQ, 145
ElementAt operator, LINQ, 145, 151
ElementAtOrDefaultValue operator, LINQ, 151
elements, LINQ, 142
#elif directive, 194
else clause, if statement, 50–51
#else directive, 194
Empty operator, LINQ, 152
encapsulation
  access modifiers for, 84
  private members by public members, 15
#endif directive, 195
#region directive, 195
EndsWith method, 31
element enumeration of query operators, LINQ, 147
elememters, 126–131
disposing after iterating over, 127
  initializing, 127
iterating over, 126
producing with iterators, 127–131
equal to operator (==), 25, 27
equality operators, 27, 134, 137
Equals method, 26, 82
#error directive, 194, 195
escape sequences, 29, 30
event keyword, 108
events, 108–113
compound assignment operators with, 45
delegate parameter
covariance with, 107
virtual, 74
<example> XML tag, 198
Except operator, LINQ, 146, 150
Exception class, 119, 120, 124
<exception> XML tag, 197
exceptions, 118–126
catching, 119, 120–121
cleaning up after, 121–123
throwing, 123–124
types of, 125
explicit conversions, 15, 22, 138
explicit event accessors, 113
explicit interface implementation, 87
expression statements, 49
expression trees, 114
expressions, 43–45
dynamic expressions, 172
lambda, 113–117
query expressions, LINQ, 153–156
extending interfaces, 87
extension methods, 139–141

F
fields, 60–61
automatic initialization of, 37
initialization order, 78
static field initializers, 69
static readonly fields, 68
finalizers, 69
finally block, 119, 121–123
Find method, arrays, 33
FindIndex method, 33
FindLastIndex method, 33
First operator, LINQ, 145, 151
FirstOrDefault operator, LINQ, 151
fixed keyword, 192
fixed statement, 190
Flags attribute, 91
float type, 20, 25, 26
floating-point types, 20
fluent syntax, 153
for loops, 32, 54
foreach loops, 32, 54, 126
form feed, escape sequence for, 29
friend assemblies, 85
from clause, query expression, 154, 158
Func delegate, 105
function members, 13, 14
functions, 180
(see also methods)
asynchronous functions, 180–189
operator functions, 136
sealing, 76
uncallable dynamically, 174
G
garbage collection, 36
generic constraints, 97
generic delegate types, 104, 107
generic methods, 94
generics, 93–101, 93
contravariance, 101
covariance, 99–101
generic types, 93
self-referencing, 98
static data, 99
subclustering, 98
unbound generic types, 96
get accessors, 65, 66
GetCustomAttribute method, 178
GetCustomAttributes method, 178
GetEnumerator method, 126
GetHashCode method, 83
GetType method, 81
GetValue method, 33
global namespace, 57
global:: qualifier, 59
goto statement, 52, 55
greater than operator (>), 27
greater than or equal to operator (>=), 27
group clause, query expression, 154
GroupBy operator, LINQ, 150, 164–165
GroupJoin operator, LINQ, 150, 159, 161

H
heap, 36
hiding inherited members, 75
horizontal tab, escape sequence for, 29

I
identifiers, 8, 9
IDynamicMetaObjectProvider (IDMOP), 168
IEnumerator interface, 86, 126, 129
IEnumerable interface, 129, 142
stdafx.h, 4
#if directive, 194
if statement, 50
implicit casting, to interface, 87
implicit conversions, 15, 22, 138
implicit parameterless constructors, 62
implicit typing, 43
#include XML tag, 199
increment operator (++), 23
indexers, 66–67
array, 32
virtual, 74
IndexOf method, 31, 33
IndexOutOfRangeException, 32
infinite loops, 54
infinity values, 25
infix notation, 44
inheritance, 71–79
initializing anonymous types, 141
initializing arrays, 33, 35
initializing enumerators, 127
initializing fields, 61
initializing objects, 63
initializing static fields, 69
InnerException property, Exception class, 124
Insert method, 31
instance constructors (see constructors)
instance members, 14
instance methods, 104, 140
instances of types, 11, 14
int type, 11, 20
integral literals, 21
integral types, 20
8- and 16-bit, 25
conversions involving, 22
division of, 23
overflow of, 23
interface generic constraint, 97
interfaces, 86–89
internal access modifier, 66, 84
Intersect operator, LINQ, 146, 150
into keyword, LINQ, 157
InvalidCastException, 73
InvalidOperationException, 125
IQueryable<> interface, 143
is operator, 74
iteration statements, 53–55
iteration variables, 54, 116
iterators, 127–131

J
jagged arrays, 34
Join method, 32
Join operator, LINQ, 150, 159
joining, LINQ, 150, 159–162
jump statements, 52, 55–56

K
keywords, 8–10

L
lambda expressions, 113–117, 188–189
lambda operator (=>), 114
language binding, 169–170
Language Integrated Query (see LINQ)
Last operator, LINQ, 145, 151
LastIndexOf method, 31, 33
LastOrDefault operator, LINQ, 151
left-associative operators, 45
Length property, arrays, 33
less than operator (<), 27
less than or equal to operator (<=), 27
let keyword, LINQ, 156–157
libraries, 7
#line directive, 195
LINQ (Language Integrated Query), 142–166
aggregating elements, 145, 149, 151
chaining query operators, 152–153
conversions, 147, 149, 152, 165–166
deferred execution, 147–148
elements, 142
extracting elements, 145
grouping, 164–165
into keyword, 157
joining, 150, 159–162
let keyword, 156–157
multiple generators, 158–159
ordering of input sequence, 144
ordering of results, 163
projecting, 144, 148, 149
quantifiers, 146, 149, 151
query continuations, 146
query expressions, 153–156
query operators, 142, 144–146, 148–152
query syntax, 143–144
sequences, 142
sets, 146, 149, 150
subqueries, 148
LINQPad, 142
<list> XML tag, 198
literals, 10
as arguments, 5
character, 29
numeric, 21
string, 30
local variables, 5, 36, 37, 43, 49
long type, 20
LongCount operator, LINQ, 151
loop statements, 53–55

M
Main method, 5, 7
Max operator, LINQ, 145, 151
member access operator (.), 10, 57
members of types, 13, 14
memory
arrays in, 32
garbage collection, 36
heap, 36
reference types in, 17
stack, 36
unsafe code manipulating, 189
value types in, 16
Message property, Exception class, 124
methods, 5, 61
anonymous methods, 117–118
arguments, 5, 37, 38–43
extension methods, 139–141
null, escape sequence for, 29
nullable types, 132–136
  boolean operators with, 135
  boxing and unboxing, 133
  conversions involving, 133, 135
  null coalescing operator (??) for, 135
  operators used with, 133–135
Nullable<T> struct, 132
numeric literals, 21
numeric suffixes, 21
numeric types, 19, 20–26, 38

O
object type, 79–83
ObjectDisposedException class, 126
OfType operator, LINQ, 152, 165–166
open types, 94
operator functions, 136
operators, 10, 44
  arithmetic operators, 23
  assignment operators, 10
  associativity of, 45
  bitwise operators, 24
  checked and unchecked, 24
  comparison operators, 27, 31, 137
  conditional operators, 28
  enums, working with, 92
  equality operators, 27, 134, 137
  for nullable types, 133–135
  increment and decrement, 23
  overloading, 136–139
  pointer-to-member operator (->), 189, 191
  precedence of, 45–48
  query operators, LINQ, 142, 144–146, 148–152
  relational operators, 134
  optional parameters, 41
  or operator, bitwise (|), 24

N
naked type generic constraint, 97
name hiding, 59
named arguments, 42
named attribute parameters, 176
namespace keyword, 57
namespaces, 6, 56–60
NaN (Not a Number) value, 25
negative infinity, 25
negative value of operator (-), 46
nested types, 92
new line, escape sequence for, 29
new modifier, 76
new operator, 14
nonpublic constructors, 63
Not a Number (NaN) value, 25
not equal to operator (!=), 27
not operator (!), 28, 194
NotImplementedException class, 125
NotSupportedException class, 125
null coalescing operator (??), 135
null literal, 18
null, escape sequence for, 29
nullable types, 132–136
  boolean operators with, 135
  boxing and unboxing, 133
  conversions involving, 133, 135
  null coalescing operator (??) for, 135
  operators used with, 133–135
Nullable<T> struct, 132
numeric literals, 21
numeric suffixes, 21
numeric types, 19, 20–26, 38

0
object type, 79–83
ObjectDisposedException class, 126
OfType operator, LINQ, 152, 165–166
open types, 94
operator functions, 136
operators, 10, 44
  arithmetic operators, 23
  assignment operators, 10
  associativity of, 45
  bitwise operators, 24
  checked and unchecked, 24
  comparison operators, 27, 31, 137
  conditional operators, 28
  enums, working with, 92
  equality operators, 27, 134, 137
  for nullable types, 133–135
  increment and decrement, 23
  overloading, 136–139
  pointer-to-member operator (->), 189, 191
  precedence of, 45–48
  query operators, LINQ, 142, 144–146, 148–152
  relational operators, 134
  optional parameters, 41
  or operator, bitwise (|), 24

Index | 211
or operator, conditional (||), 28, 194
or self by operator (|=), 46
orderby keyword, LINQ, 163
OrderBy operator, LINQ, 150
OrderByDescending operator, LINQ, 150
out modifier, 38, 40
outer variables, capturing, 115
overflow, 23, 24, 46
OverflowException, 24
overloading constructors, 62
overloading dynamic members, 173
overloading methods, 61, 78
overloading operators, 136–139
overridden function members accessing, 76
override modifier, 74

P
PadLeft method, 31
PadRight method, 31
<para> XML tag, 199
parallelism, with asynchronous functions, 187–188
<param> XML tag, 197
<paramref> XML tag, 198
parameterless constructor constraint, 97
parameterless constructor generic constraint, 97
parameterless constructors, 62, 78
parameters, 5, 36, 38–43
attribute parameters, 176
type parameters, 93, 94, 95, 96
params modifier, 40
partial methods, 70
partial types, 69
passing by reference, 40
passing by value, 39
pattern for events, 109
<permission> XML tag, 197
pinning, 190
placeholder types, 93
plug-in methods, 102
pointer-to-member operator (->), 189, 191
pointers, 189–193
polymorphism, 72
positional attribute parameters, 176
positive infinity, 25
positive value of operator (+), 46
#pragma warning directive, 195
precedence of operators, 45–48
predefined types, 11, 13, 19
preprocessor directives, 193–196
primary operators, 44
primitive types, 19
private access modifier, 66, 84
private members, 15
projecting, LINQ, 144, 148, 149
properties, 64–66
protected access modifier, 84
protected internal access modifier, 85
public access modifier, 15, 84
public members, 15
punctuators, 10

Q
quantifiers, LINQ, 146, 149, 151
queries, LINQ, 143–144
query continuations, LINQ, 157
query expressions, LINQ, 153–156
query operators, LINQ, 142, 144–146, 148–152

R
Range operator, LINQ, 152
Rank property, arrays, 33
read-only indexers, 67
read-only properties, 65
readonly modifier, fields, 61
real literals, 21
real number types, 20, 22
rectangular arrays, 34
ref modifier, 38, 40
refactoring, 5
reference conversions, 72
reference generic constraint, 97
reference types, 17, 19
reference, passing arguments by, 40
ReferenceEquals method, 83
#region directive, 195
relational operators, 134
remainder operator (%), 23
<!-- remarks --> XML tag, 197
Remove method, 31
Repeat operator, LINQ, 152
return statement, 56, 130
return, escape sequence for, 29
<!-- returns --> XML tag, 197
Reverse operator, LINQ, 144, 150
right-associative operators, 45
rounding errors, 26
runtime type checking, 73, 81
RuntimeBinderException, 170

S
sbyte type, 20, 25
scope in namespaces, 58
scope of local variables, 49
sealed keyword, 76
searching strings, 31
<!-- see --> XML tag, 198
<!-- seealso --> XML tag, 198
select clause, query expression, 154
Select operator, LINQ, 144, 149
selection statements, 50–53
SelectMany operator, LINQ, 150, 158
SequenceEquals operator, LINQ, 146, 151
sequences, LINQ, 142
serialization, 175
set accessors, 65, 66
sets, LINQ, 146, 149, 150
SetValue method, 33
shift operators, 24
short type, 20, 25
short-circuiting, 28
signature of method, 61
Single operator, LINQ, 145, 151
SingleOrDefault operator, LINQ, 151
16-bit integral types, 25
Skip operator, LINQ, 144, 149
SkipWhile operator, LINQ, 149
Sort method, 33
Split method, 32
stack, 36
stackalloc keyword, 192
StackTrace property, Exception class, 124
StartsWith method, 31
statement blocks, 5, 10, 49
statements, 5, 49–56
(see also specific statements)
declaration statements, 49
expression statements, 49
iteration statements, 53–55
jump statements, 55–56
selection statements, 50–53
switch statement, 52–53
static binding, 167–168
static classes, 14, 69
static constructors, 68
static data, 99
static field initializers, 69
static fields, 37
static members, 14
static readonly fields, 68
static type checking, 81
static types, 43
storage (see memory)
string concatenation operator (+), 31
string literals, 30
string type, 12, 30–32, 67
struct generic constraint, 97
struct keyword, 16
structs, 83–84
subclasses, 72, 75
<table>
<thead>
<tr>
<th>Index</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>this keyword</td>
<td>62</td>
</tr>
<tr>
<td>this modifier, extension methods</td>
<td>139</td>
</tr>
<tr>
<td>this property, indexers</td>
<td>67</td>
</tr>
<tr>
<td>this reference</td>
<td>64</td>
</tr>
<tr>
<td>throw statement</td>
<td>123</td>
</tr>
<tr>
<td>throwing exceptions</td>
<td>123–124</td>
</tr>
<tr>
<td>ToArray operator</td>
<td>LINQ, 147, 152</td>
</tr>
<tr>
<td>ToDictionary operator</td>
<td>LINQ, 147, 152</td>
</tr>
<tr>
<td>ToList operator</td>
<td>LINQ, 147, 152</td>
</tr>
<tr>
<td>ToLookup operator</td>
<td>LINQ, 147, 152</td>
</tr>
<tr>
<td>ToLower method</td>
<td>32</td>
</tr>
<tr>
<td>ToString method</td>
<td>83</td>
</tr>
<tr>
<td>ToUpper method</td>
<td>32</td>
</tr>
<tr>
<td>Trim method</td>
<td>31</td>
</tr>
<tr>
<td>TrimStart method</td>
<td>31</td>
</tr>
<tr>
<td>try statement</td>
<td>118–126</td>
</tr>
<tr>
<td>type arguments</td>
<td>93</td>
</tr>
<tr>
<td>type checking</td>
<td>73, 81, 142</td>
</tr>
<tr>
<td>Type class</td>
<td>81</td>
</tr>
<tr>
<td>type parameters</td>
<td>93, 94, 95, 96</td>
</tr>
<tr>
<td>type safety</td>
<td>93, 100, 169</td>
</tr>
<tr>
<td>type of operator</td>
<td>81, 96</td>
</tr>
<tr>
<td>types</td>
<td>11–20</td>
</tr>
<tr>
<td>aliasing</td>
<td>60</td>
</tr>
<tr>
<td>anonymous types</td>
<td>141</td>
</tr>
<tr>
<td>arrays</td>
<td>32–36</td>
</tr>
<tr>
<td>bool type</td>
<td>27, 135</td>
</tr>
<tr>
<td>closed types</td>
<td>94</td>
</tr>
<tr>
<td>compatibility of, with delegates</td>
<td>106–108</td>
</tr>
<tr>
<td>conversions (see conversions)</td>
<td>custom types</td>
</tr>
<tr>
<td>default values for</td>
<td>38</td>
</tr>
<tr>
<td>generic types</td>
<td>93, 96</td>
</tr>
<tr>
<td>instantiating</td>
<td>14</td>
</tr>
<tr>
<td>nested</td>
<td>92</td>
</tr>
<tr>
<td>nullable types</td>
<td>132–136</td>
</tr>
<tr>
<td>numeric types</td>
<td>19, 20–26</td>
</tr>
<tr>
<td>open types</td>
<td>94</td>
</tr>
<tr>
<td>partial types</td>
<td>69</td>
</tr>
<tr>
<td>predefined types</td>
<td>11, 13, 19</td>
</tr>
<tr>
<td>primitive types</td>
<td>19</td>
</tr>
<tr>
<td>reference types</td>
<td>17, 19</td>
</tr>
<tr>
<td>string type</td>
<td>30–32</td>
</tr>
<tr>
<td>value types</td>
<td>16, 19</td>
</tr>
<tr>
<td>Uint type</td>
<td>20</td>
</tr>
<tr>
<td>ulong type</td>
<td>20</td>
</tr>
<tr>
<td>unary operators</td>
<td>44</td>
</tr>
<tr>
<td>unbound generic types</td>
<td>96</td>
</tr>
<tr>
<td>unboxing</td>
<td>80, 133</td>
</tr>
<tr>
<td>unchecked operator</td>
<td>24</td>
</tr>
<tr>
<td>#undef directive</td>
<td>194</td>
</tr>
<tr>
<td>Union operator</td>
<td>LINQ, 146, 150</td>
</tr>
<tr>
<td>unsafe code</td>
<td>189–193</td>
</tr>
<tr>
<td>unsafe keyword</td>
<td>190</td>
</tr>
<tr>
<td>upcasting</td>
<td>72, 79</td>
</tr>
<tr>
<td>ushort type</td>
<td>20, 25</td>
</tr>
</tbody>
</table>
using directive, 6, 58
using statement, 122, 127

V
value generic constraint, 97
value types, 16, 19
value, passing arguments by, 39
var keyword, 43
variables, 11, 36
  as expressions, 43
declaring, 49
definite assignment, 37
identifiers for, 8
implicit typing of, 43
local variables, 5, 36, 37, 43
scope of local variables, 49
storage of, 36
verbatim string literals, 30
vertical tab, escape sequence for, 29
virtual function members, 74–75
virtual interface implementation, 88
virtual keyword, 74
void expressions, 44
void return type
  methods, 61
  multicast delegates, 104
void* pointers, 193

W
#warning directive, 194, 195
Where operator, LINQ, 143, 149
while loops, 53
write-only properties, 65
WriteLine method, 5, 6

X
XML documentation, 196–199
xor by self operator (^=), 46
xor operator, bitwise (^), 24

Y
yield break statement, 130
yield statement, 128, 129
Z
zero, division by, 25
Zip operator, LINQ, 150, 162